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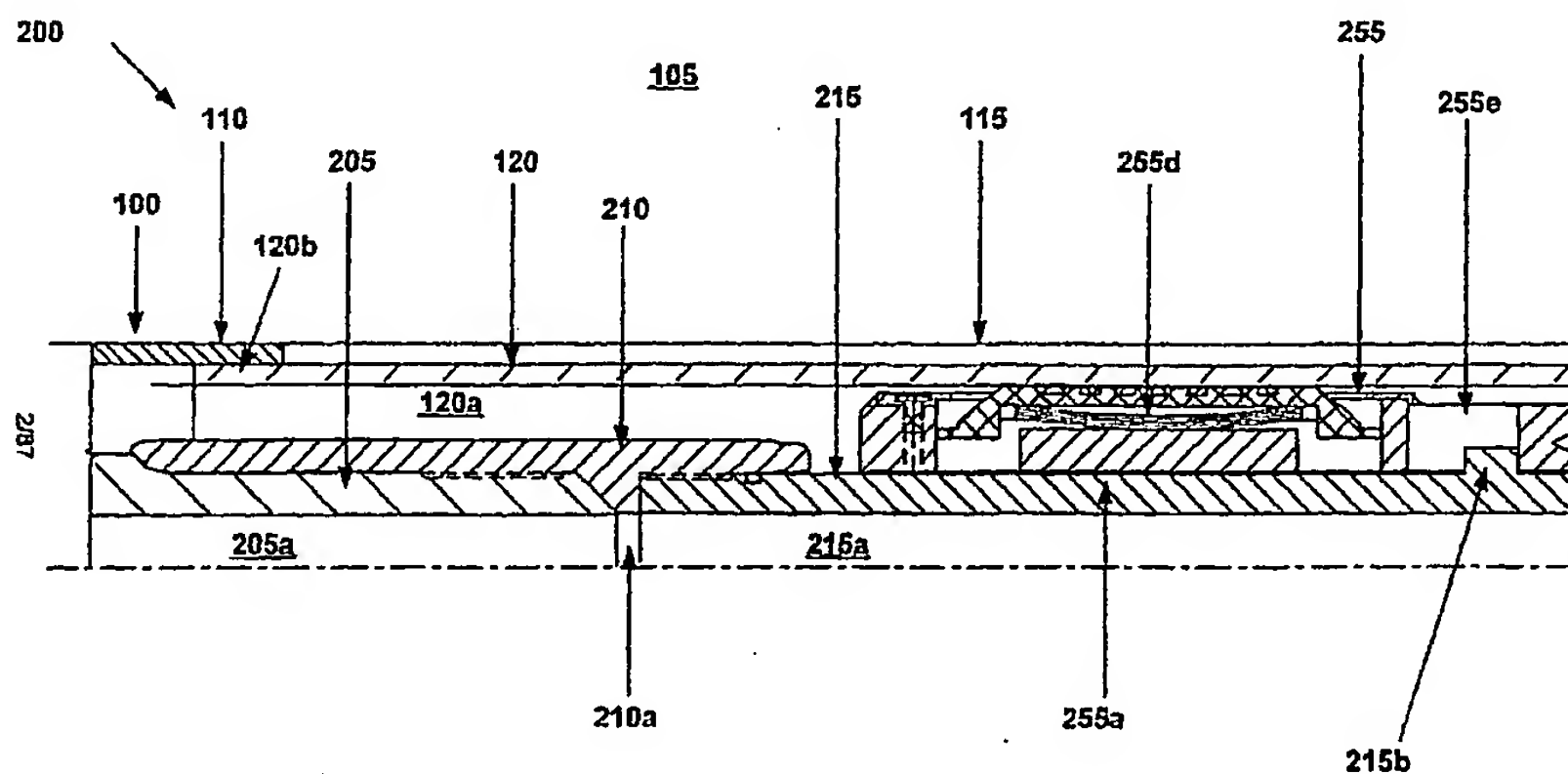
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(54) Title: APPARATUS AND METHOD FOR RADially EXPANDING A WELLBORE CASING USING AN EXPANSION SYSTEM



(57) Abstract: An apparatus and method for radially expanding a wellbore using an expansion system, the expansion system movable from a first small diameter configuration to a second larger diameter configuration.

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APPARATUS AND METHOD FOR RADially EXPANDING A WELLBORE CASING USING AN  
EXPANSION SYSTEM

## Cross Reference To Related Applications

[0001] This application claims the benefit of the filing date of US provisional patent application serial number 60/663,913, attorney docket number 25791.32, filed on March 21, 2005, the disclosure of which is incorporated herein by reference.

[0002] The present application is a continuation-in-part of U.S. utility patent application serial no. 10/488,574, attorney docket no. 25791.58.05, filed on 3/7/2004, which is the National Stage filing of PCT patent application serial no. PCT/US02/25608, attorney docket no. 25791.58.02, filed on August 13, 2002, which claimed the benefit of the filing date of U.S. provisional patent application serial no. 60/318,021, attorney docket no. 25791.58, filed on 9/7/2001, the disclosure of which is incorporated herein by reference.

[0003] This application is related to the following co-pending applications: (1) U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, which claims priority from provisional application 60/121,702, filed on 2/25/99, (3) U.S. Patent Number 6,823,937, which was filed as U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (4) U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (5) U.S. patent application serial no. 10/169,434, attorney docket no. 25791.10.04, filed on 7/1/02, which claims priority from provisional application 60/183,546, filed on 2/18/00, (6) U.S. patent no. 6,640,903 which was filed as U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (7) U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (8) U.S. patent number 6,575,240, which was filed as patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, which claims priority from provisional application 60/121,907, filed on 2/26/99, (9) U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (10) U.S. patent application serial no. 09/981,916, attorney docket no. 25791.18, filed on 10/18/01 as a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (11) U.S. patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (12) U.S. patent application serial no. 10/030,593, attorney docket no. 25791.25.08, filed on 1/8/02, which claims priority from provisional application 60/146,203, filed on 7/29/99, (13) U.S. provisional patent application serial no. 60/143,039, attorney docket no. 25791.26, filed on 7/9/99, (14) U.S. patent application serial no. 10/111,982, attorney docket no. 25791.27.08, filed on 4/30/02, which claims priority from provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (15) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (16) U.S. provisional patent application serial no. 60/438,828, attorney docket no. 25791.31, filed on

1/9/03, (17) U.S. patent number 6,564,875, which was filed as application serial no. 09/679,907, attorney docket no. 25791.34.02, on 10/5/00, which claims priority from provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (18) U.S. patent application serial no. 10/089,419, filed on 3/27/02, attorney docket no. 25791.36.03, which claims priority from provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (19) U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (20) U.S. patent application serial no. 10/303,992, filed on 11/22/02, attorney docket no. 25791.38.07, which claims priority from provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (21) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (22) U.S. provisional patent application serial no. 60/455,051, attorney docket no. 25791.40, filed on 3/14/03, (23) PCT application US02/2477, filed on 6/26/02, attorney docket no. 25791.44.02, which claims priority from U.S. provisional patent application serial no. 60/303,711, attorney docket no. 25791.44, filed on 7/6/01, (24) U.S. patent application serial no. 10/311,412, filed on 12/12/02, attorney docket no. 25791.45.07, which claims priority from provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (25) U.S. patent application serial no. 10/, filed on 12/18/02, attorney docket no. 25791.46.07, which claims priority from provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (26) U.S. patent application serial no. 10/322,947, filed on 1/22/03, attorney docket no. 25791.47.03, which claims priority from provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (27) U.S. patent application serial no. 10/406,648, filed on 3/31/03, attorney docket no. 25791.48.06, which claims priority from provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (28) PCT application US02/04353, filed on 2/14/02, attorney docket no. 25791.50.02, which claims priority from U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (29) U.S. patent application serial no. 10/465,835, filed on 6/13/03, attorney docket no. 25791.51.06, which claims priority from provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (30) U.S. patent application serial no. 10/465,831, filed on 6/13/03, attorney docket no. 25791.52.06, which claims priority from U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (31) U.S. provisional patent application serial no. 60/452,303, filed on 3/5/03, attorney docket no. 25791.53, (32) U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (33) U.S. patent number 6,561,227, which was filed as patent application serial number 09/852,026, filed on 5/9/01, attorney docket no. 25791.56, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (34) U.S. patent application serial number 09/852,027, filed on 5/9/01, attorney docket no. 25791.57, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (35) PCT Application US02/25608, attorney docket no. 25791.58.02, filed on 8/13/02, which claims priority from provisional application 60/318,021, filed on 9/7/01, attorney docket no. 25791.58, (36) PCT Application US02/24399, attorney docket no. 25791.59.02, filed on 8/1/02, which claims priority from U.S.

provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (37) PCT Application US02/29856, attorney docket no. 25791.60.02, filed on 9/19/02, which claims priority from U.S. provisional patent application serial no. 60/326,886, attorney docket no. 25791.60, filed on 10/3/2001, (38) PCT Application US02/20256, attorney docket no. 25791.61.02, filed on 6/26/02, which claims priority from U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (39) U.S. patent application serial no. 09/962,469, filed on 9/25/01, attorney docket no. 25791.62, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (40) U.S. patent application serial no. 09/962,470, filed on 9/25/01, attorney docket no. 25791.63, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (41) U.S. patent application serial no. 09/962,471, filed on 9/25/01, attorney docket no. 25791.64, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (42) U.S. patent application serial no. 09/962,467, filed on 9/25/01, attorney docket no. 25791.65, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (43) U.S. patent application serial no. 09/962,468, filed on 9/25/01, attorney docket no. 25791.66, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (44) PCT application US 02/25727, filed on 8/14/02, attorney docket no. 25791.67.03, which claims priority from U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, and U.S. provisional patent application serial no. 60/318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (45) PCT application US 02/39425, filed on 12/10/02, attorney docket no. 25791.68.02, which claims priority from U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001, (46) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (47) U.S. utility patent application serial no. 10/516,467, attorney docket no. 25791.70, filed on 12/10/01, which is a continuation application of U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (48) PCT application US 03/00609, filed on 1/9/03, attorney docket no. 25791.71.02, which claims priority from U.S. provisional patent application serial no. 60/357,372, attorney docket no. 25791.71, filed on 2/15/02, (49) U.S. patent application serial no. 10/074,703, attorney docket no. 25791.74, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (50) U.S. patent application serial no. 10/074,244, attorney docket no. 25791.75, filed on 2/12/02, which is a divisional of U.S.



patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (51) U.S. patent application serial no. 10/076,660, attorney docket no. 25791.76, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (52) U.S. patent application serial no. 10/076,661, attorney docket no. 25791.77, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (53) U.S. patent application serial no. 10/076,659, attorney docket no. 25791.78, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (54) U.S. patent application serial no. 10/078,928, attorney docket no. 25791.79, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (55) U.S. patent application serial no. 10/078,922, attorney docket no. 25791.80, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (56) U.S. patent application serial no. 10/078,921, attorney docket no. 25791.81, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (57) U.S. patent application serial no. 10/261,928, attorney docket no. 25791.82, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (58) U.S. patent application serial no. 10/079,276, attorney docket no. 25791.83, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (59) U.S. patent application serial no. 10/262,009, attorney docket no. 25791.84, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (60) U.S. patent application serial no. 10/092,481, attorney docket no. 25791.85, filed on 3/7/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (61) U.S. patent application serial no. 10/261,926, attorney docket no. 25791.86, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (62) PCT application US 02/36157, filed on 11/12/02, attorney docket no. 25791.87.02, which claims priority from U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/01, (63) PCT application US 02/36267, filed on 11/12/02, attorney docket no. 25791.88.02, which claims priority from U.S. provisional patent application serial no. 60/339,013, attorney docket no. 25791.88, filed on 11/12/01, (64) PCT application US 03/11765, filed on 4/16/03, attorney docket no. 25791.89.02, which claims priority from U.S. provisional patent application serial no. 60/383,917, attorney docket no. 25791.89, filed on

5/29/02, (65) PCT application US 03/15020, filed on 5/12/03, attorney docket no. 25791.90.02, which claims priority from U.S. provisional patent application serial no. 60/391,703, attorney docket no. 25791.90, filed on 6/26/02, (66) PCT application US 02/39418, filed on 12/10/02, attorney docket no. 25791.92.02, which claims priority from U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/02, (67) PCT application US 03/06544, filed on 3/4/03, attorney docket no. 25791.93.02, which claims priority from U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/02, (68) U.S. patent application serial no. 10/331,718, attorney docket no. 25791.94, filed on 12/30/02, which is a divisional U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (69) PCT application US 03/04837, filed on 2/29/03, attorney docket no. 25791.95.02, which claims priority from U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/02, (70) U.S. patent application serial no. 10/261,927, attorney docket no. 25791.97, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (71) U.S. patent application serial no. 10/262,008, attorney docket no. 25791.98, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (72) U.S. patent application serial no. 10/261,925, attorney docket no. 25791.99, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (73) U.S. patent application serial no. 10/199,524, attorney docket no. 25791.100, filed on 7/19/02, which is a continuation of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (74) PCT application US 03/10144, filed on 3/28/03, attorney docket no. 25791.101.02, which claims priority from U.S. provisional patent application serial no. 60/372,632, attorney docket no. 25791.101, filed on 4/15/02, (75) U.S. provisional patent application serial no. 60/412,542, attorney docket no. 25791.102, filed on 9/20/02, (76) PCT application US 03/14153, filed on 5/6/03, attorney docket no. 25791.104.02, which claims priority from U.S. provisional patent application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/02, (77) PCT application US 03/19993, filed on 6/24/03, attorney docket no. 25791.106.02, which claims priority from U.S. provisional patent application serial no. 60/397,284, attorney docket no. 25791.106, filed on 7/19/02, (78) PCT application US 03/13787, filed on 5/5/03, attorney docket no. 25791.107.02, which claims priority from U.S. provisional patent application serial no. 60/387,486, attorney docket no. 25791.107, filed on 6/10/02, (79) PCT application US 03/18530, filed on 6/11/03, attorney docket no. 25791.108.02, which claims priority from U.S. provisional patent application serial no. 60/387,961, attorney docket no. 25791.108, filed on 6/12/02, (80) PCT application US 03/20694, filed on 7/1/03, attorney docket no. 25791.110.02, which claims priority from U.S. provisional patent application serial no. 60/398,061, attorney docket no. 25791.110, filed on 7/24/02, (81) PCT application US 03/20870, filed on 7/2/03, attorney docket no. 25791.111.02, which claims priority from U.S. provisional patent application serial no. 60/399,240, attorney docket no. 25791.111, filed on 7/29/02, (82) U.S. provisional patent application serial no. 60/412,487, attorney docket no. 25791.112, filed on 9/20/02, (83) U.S. provisional patent application serial no. 60/412,488, attorney docket no. 25791.114, filed on 9/20/02, (84) U.S. patent application serial no. 10/280,356, attorney docket no. 25791.115, filed on 10/25/02,

which is a continuation of U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (85) U.S. provisional patent application serial no. 60/412,177, attorney docket no. 25791.117, filed on 9/20/02, (86) U.S. provisional patent application serial no. 60/412,653, attorney docket no. 25791.118, filed on 9/20/02, (87) U.S. provisional patent application serial no. 60/405,610, attorney docket no. 25791.119, filed on 8/23/02, (88) U.S. provisional patent application serial no. 60/405,394, attorney docket no. 25791.120, filed on 8/23/02, (89) U.S. provisional patent application serial no. 60/412,544, attorney docket no. 25791.121, filed on 9/20/02, (90) PCT application US 03/24779, filed on 8/8/03, attorney docket no. 25791.125.02, which claims priority from U.S. provisional patent application serial no. 60/407,442, attorney docket no. 25791.125, filed on 8/30/02, (91) U.S. provisional patent application serial no. 60/423,363, attorney docket no. 25791.126, filed on 12/10/02, (92) U.S. provisional patent application serial no. 60/412,196, attorney docket no. 25791.127, filed on 9/20/02, (93) U.S. provisional patent application serial no. 60/412,187, attorney docket no. 25791.128, filed on 9/20/02, (94) U.S. provisional patent application serial no. 60/412,371, attorney docket no. 25791.129, filed on 9/20/02, (95) U.S. patent application serial no. 10/382,325, attorney docket no. 25791.145, filed on 3/5/03, which is a continuation of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (96) U.S. patent application serial no. 10/624,842, attorney docket no. 25791.151, filed on 7/22/03, which is a divisional of U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (97) U.S. provisional patent application serial no. 60/431,184, attorney docket no. 25791.157, filed on 12/5/02, (98) U.S. provisional patent application serial no. 60/448,526, attorney docket no. 25791.185, filed on 2/18/03, (99) U.S. provisional patent application serial no. 60/461,539, attorney docket no. 25791.186, filed on 4/9/03, (100) U.S. provisional patent application serial no. 60/462,750, attorney docket no. 25791.193, filed on 4/14/03, (101) U.S. provisional patent application serial no. 60/436,106, attorney docket no. 25791.200, filed on 12/23/02, (102) U.S. provisional patent application serial no. 60/442,942, attorney docket no. 25791.213, filed on 1/27/03, (103) U.S. provisional patent application serial no. 60/442,938, attorney docket no. 25791.225, filed on 1/27/03, (104) U.S. provisional patent application serial no. 60/418,687, attorney docket no. 25791.228, filed on 4/18/03, (105) U.S. provisional patent application serial no. 60/454,896, attorney docket no. 25791.236, filed on 3/14/03, (106) U.S. provisional patent application serial no. 60/450,504, attorney docket no. 25791.238, filed on 2/26/03, (107) U.S. provisional patent application serial no. 60/451,152, attorney docket no. 25791.239, filed on 3/9/03, (108) U.S. provisional patent application serial no. 60/455,124, attorney docket no. 25791.241, filed on 3/17/03, (109) U.S. provisional patent application serial no. 60/453,678, attorney docket no. 25791.253, filed on 3/11/03, (110) U.S. patent application serial no. 10/421,682, attorney docket no. 25791.256, filed on 4/23/03, which is a continuation of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (111) U.S. provisional patent application serial no. 60/457,965, attorney docket no. 25791.260, filed on 3/27/03, (112) U.S. provisional patent application serial no. 60/455,718, attorney docket no. 25791.262, filed on 3/18/03, (113) U.S. patent number 6,550,821, which was filed as patent application serial no. 09/811,734, filed on 3/19/01, (114) U.S. patent application serial no. 10/436,467, attorney docket no. 25791.268, filed on 5/12/03, which is a continuation of U.S.



patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (115) U.S. provisional patent application serial no. 60/459,776, attorney docket no. 25791.270, filed on 4/2/03, (116) U.S. provisional patent application serial no. 60/461,094, attorney docket no. 25791.272, filed on 4/8/03, (117) U.S. provisional patent application serial no. 60/461,038, attorney docket no. 25791.273, filed on 4/7/03, (118) U.S. provisional patent application serial no. 60/463,586, attorney docket no. 25791.277, filed on 4/17/03, (119) U.S. provisional patent application serial no. 60/472,240, attorney docket no. 25791.286, filed on 5/20/03, (120) U.S. patent application serial no. 10/619,285, attorney docket no. 25791.292, filed on 7/14/03, which is a continuation-in-part of U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (121) U.S. utility patent application serial no. 10/418,688, attorney docket no. 25791.257, which was filed on 4/18/03, as a division of U.S. utility patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99; (122) PCT patent application serial no. PCT/US2004/06246, attorney docket no. 25791.238.02, filed on 2/26/2004; (123) PCT patent application serial number PCT/US2004/08170, attorney docket number 25791.40.02, filed on 3/15/04; (124) PCT patent application serial number PCT/US2004/08171, attorney docket number 25791.236.02, filed on 3/15/04; (125) PCT patent application serial number PCT/US2004/08073, attorney docket number 25791.262.02, filed on 3/18/04; (126) PCT patent application serial number PCT/US2004/07711, attorney docket number 25791.253.02, filed on 3/11/2004; (127) PCT patent application serial number PCT/US2004/029025, attorney docket number 25791.260.02, filed on 3/26/2004; (128) PCT patent application serial number PCT/US2004/010317, attorney docket number 25791.270.02, filed on 4/2/2004; (129) PCT patent application serial number PCT/US2004/010712, attorney docket number 25791.272.02, filed on 4/6/2004; (130) PCT patent application serial number PCT/US2004/010762, attorney docket number 25791.273.02, filed on 4/6/2004; (131) PCT patent application serial number PCT/US2004/011973, attorney docket number 25791.277.02, filed on 4/15/2004; (132) U.S. provisional patent application serial number 60/495056, attorney docket number 25791.301, filed on 8/14/2003; (133) U.S. provisional patent application serial number 60/600679, attorney docket number 25791.194, filed on 8/11/2004; (134) PCT patent application serial number PCT/US2005/027318, attorney docket number 25791.329.02, filed on 7/29/2005; (135) PCT patent application serial number PCT/US2005/028936, attorney docket number 25791.338.02, filed on 8/12/2005; (136) PCT patent application serial number PCT/US2005/028669, attorney docket number 25791.194.02, filed on 8/11/2005; (137) PCT patent application serial number PCT/US2005/028453, attorney docket number 25791.371, filed on 8/11/2005; (138) PCT patent application serial number PCT/US2005/028641, attorney docket number 25791.372, filed on 8/11/2005; (139) PCT patent application serial number PCT/US2005/028819, attorney docket number 25791.373, filed on 8/11/2005; (140) PCT patent application serial number PCT/US2005/028446, attorney docket number 25791.374, filed on 8/11/2005; (141) PCT patent application serial number PCT/US2005/028642, attorney docket number 25791.375, filed on 8/11/2005; (142) PCT patent application serial number PCT/US2005/028451, attorney docket number 25791.376, filed on 8/11/2005, and (143). PCT patent application serial number PCT/US2005/028473, attorney docket number 25791.377, filed on 8/11/2005, (144) U.S. utility patent application serial number 10/546082, attorney docket number 25791.378, filed on 8/16/2005, (145) U.S. utility patent



application serial number 10/546076, attorney docket number 25791.379, filed on 8/16/2005, (146) U.S. utility patent application serial number 10/545936, attorney docket number 25791.380, filed on 8/16/2005, (147) U.S. utility patent application serial number 10/546079, attorney docket number 25791.381, filed on 8/16/2005 (148) U.S. utility patent application serial number 10/545941, attorney docket number 25791.382, filed on 8/16/2005, (149) U.S. utility patent application serial number 546078, attorney docket number 25791.383, filed on 8/16/2005, filed on 8/11/2005., (150) U.S. utility patent application serial number 10/545941, attorney docket number 25791.185.05, filed on 8/16/2005, (151) U.S. utility patent application serial number 11/249967, attorney docket number 25791.384, filed on 10/13/2005, (152) U.S. provisional patent application serial number 60/734302, attorney docket number 25791.24, filed on 11/7/2005, (153) U.S. provisional patent application serial number 60/725181, attorney docket number 25791.184, filed on 10/11/2005, (154) PCT patent application serial number PCT/US2005/023391, attorney docket number 25791.299.02 filed 6/29/2005 which claims priority from U.S. provisional patent application serial number 60/585370, attorney docket number 25791.299, filed on 7/2/2004, (155) U.S. provisional patent application serial number 60/721579, attorney docket number 25791.327, filed on 9/28/2005, (156) U.S. provisional patent application serial number 60/717391, attorney docket number 25791.214, filed on 9/15/2005, (157) U.S. provisional patent application serial number 60/702935, attorney docket number 25791.133, filed on 7/27/2005, (158) U.S. provisional patent application serial number 60/663913, attorney docket number 25791.32, filed on 3/21/2005, (159) U.S. provisional patent application serial number 60/652564, attorney docket number 25791.348, filed on 2/14/2005, (160) U.S. provisional patent application serial number 60/645840, attorney docket number 25791.324, filed on 1/21/2005, (161) PCT patent application serial number PCT/US2005/\_\_\_\_\_, attorney docket number 25791.326.02, filed on 11/29/2005 which claims priority from U.S. provisional patent application serial number 60/631703, attorney docket number 25791.326, filed on 11/30/2004, (162) U.S. provisional patent application serial number \_\_\_\_\_, attorney docket number 25791.339, filed on 12/22/2005, (163) U.S. National Stage application serial no. 10/548934, attorney docket no. 25791.253.05, filed on 9/12/2005; (164) U.S. National Stage application serial no. 10/549410, attorney docket no. 25791.262.05, filed on 9/13/2005; (165) U.S. Provisional Patent Application No. 60/717391, attorney docket no. 25791.214 filed on 9/15/2005; (166) U.S. National Stage application serial no. 10/550906, attorney docket no. 25791.260.06, filed on 9/27/2005; (167) U.S. National Stage application serial no. 10/551880, attorney docket no. 25791.270.06, filed on 9/30/2005; (168) U.S. National Stage application serial no. 10/552253, attorney docket no. 25791.273.06, filed on 10/4/2005; (169) U.S. National Stage application serial no. 10/552790, attorney docket no. 25791.272.06, filed on 10/11/2005; (170) U.S. Provisional Patent Application No. 60/725181, attorney docket no. 25791.184 filed on 10/11/2005; (171) U.S. National Stage application serial no. 10/553094, attorney docket no. 25791.193.03, filed on 10/13/2005; (172) U.S. National Stage application serial no. 10/553566, attorney docket no. 25791.277.06, filed on 10/17/05; (173) PCT Patent Application No. PCT/US2006/\_\_\_\_\_, attorney docket no. 25791.324.02 filed on 1/20/06, and (174) PCT Patent Application No. PCT/US2006/\_\_\_\_\_, attorney docket no. 25791.348.02 filed on 2/9/06; (175) U.S. Utility Patent application serial no. \_\_\_\_\_, attorney docket no. 25791.386, filed on 2/17/06, (176) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.301.06, filed on \_\_\_\_\_, (177) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.137.04, filed on \_\_\_\_\_, (178) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.215.06, filed on \_\_\_\_\_.

#### Background

[0004] This invention relates generally to oil and gas exploration, and in particular to forming and repairing wellbore casings to facilitate oil and gas exploration.

[0005] Conventionally, when a wellbore is created, a number of casings are installed in the borehole to prevent collapse of the borehole wall and to prevent undesired outflow of drilling fluid into the formation or inflow of fluid from the formation into the borehole. The borehole is drilled in intervals whereby a casing which is to be installed in a lower borehole interval is lowered through a previously installed casing of an upper borehole interval. As a consequence of this procedure the casing of the lower interval is of smaller diameter than the casing of the upper interval. Thus, the casings are in a nested arrangement with casing diameters decreasing in downward direction. Cement annuli are provided between the outer surfaces of the casings and the borehole wall to seal the casings from the borehole wall. As a consequence of this nested arrangement a relatively large borehole diameter is required at the upper part of the wellbore. Such a large borehole diameter involves increased costs due to heavy casing handling equipment, large drill bits and increased volumes of drilling fluid and drill cuttings. Moreover, increased drilling rig time is involved due to required cement pumping, cement hardening, required equipment changes due to large variations in hole diameters drilled in the course of the well, and the large volume of cuttings drilled and removed.

[0006] The present invention is directed to overcoming one or more of the limitations of the existing procedures for forming and/or repairing wellbore casings.

#### Brief Description of the Drawings

[0007] Fig. 1 is a cross-sectional view illustrating an embodiment of the placement of an apparatus for radially expanding a tubular member within a tubular member within a borehole within a subterranean formation.

[0008] Fig. 1a is a fragmentary cross-sectional view illustrating the placement of a section of the apparatus for radially expanding a tubular member within a tubular member within a borehole within a subterranean formation of Fig. 1.

[0009] Fig. 1b is a fragmentary cross-sectional view illustrating the placement of a section of the apparatus for radially expanding a tubular member within a tubular member within a borehole within a subterranean formation of Fig. 1.

[00010] Fig. 1c is a fragmentary cross-sectional view illustrating the placement of a section of the apparatus for radially expanding a tubular member within a tubular member within a borehole within a subterranean formation of Fig. 1.

[00011] Fig. 1d is a fragmentary cross-sectional view illustrating the placement of a section of the apparatus for radially expanding a tubular member within a tubular member within a borehole within a subterranean formation of Fig. 1.

[00012] Fig. 1e is a cross-sectional view illustrating an embodiment of the expansion cone support body of the apparatus of Figs. 1, 1a, 1b, 1c, and 1d.

[00013] Fig. 1f is a cross-sectional view illustrating an embodiment of the expansion cone support body of Fig. 1e.

[00014] Fig. 1g is a side view illustrating an embodiment of an expansion cone segment for use in the apparatus of Figs. 1, 1a, 1b, 1c, and 1d.

[00015] Fig. 1h is a front view illustrating an embodiment of the expansion cone segment of Fig. 1g.

[00016] Fig. 1i is a top view illustrating an embodiment of the expansion cone segment of Fig. 1g.

[00017] Fig. 1j is a top view illustrating an embodiment of interlocking expansion cone segments for use in the apparatus of Figs. 1, 1a, 1b, 1c, and 1d.

[00018] Fig. 1k is a top fragmentary circumferential view illustrating an embodiment of the coupling arrangement between the expansion cone segments and the split ring collar for use in the apparatus of Figs. 1, 1a, 1b, 1c, and 1d.

[00019] Fig. 1l is a top schematic view illustrating an embodiment of the coupling between the J-slots of the drag blocks and the lugs of the tubular support member of the apparatus of Figs. 1, 1a, 1b, 1c, and 1d.

[00020] Fig. 1m is a top schematic view illustrating an embodiment of the coupling between the J-slots of the drag blocks and the lugs of the tubular support member of the apparatus of Figs. 1, 1a, 1b, 1c, and 1d.

[00021] Fig. 2 is a cross-sectional view illustrating an embodiment of the apparatus of Figs. 1, 1a, 1b, 1c, and 1d during the radial expansion of the tubular member within the borehole within the subterranean formation.

[00022] Fig. 2a is a fragmentary cross-sectional view illustrating an embodiment of a section of the apparatus of Figs. 1, 1a, 1b, 1c, and 1d during the radial expansion of the tubular member within the borehole within the subterranean formation.

[00023] Fig. 2b is a fragmentary cross-sectional view illustrating an embodiment of a section of the apparatus of Figs. 1, 1a, 1b, 1c, and 1d during the radial expansion of the tubular member within the borehole within the subterranean formation.

[00024] Fig. 2c is a fragmentary cross-sectional view illustrating an embodiment of a section of the apparatus of Figs. 1, 1a, 1b, 1c, and 1d during the radial expansion of the tubular member within the borehole within the subterranean formation.

[00025] Fig. 2d is a fragmentary cross-sectional view illustrating an embodiment of a section of the apparatus of Figs. 1, 1a, 1b, 1c, and 1d during the radial expansion of the tubular member within the borehole within the subterranean formation.

[00026] Fig. 2e is a top schematic view illustrating an embodiment of the J-slots of the drag blocks and the lugs of the tubular support member of the apparatus of Figs. 2, 2a, 2b, 2c, and 2d.

[00027] Fig. 2f is a top schematic view illustrating an embodiment of the J-slots of the drag blocks and the lugs of the tubular support member of the apparatus of Figs. 2, 2a, 2b, 2c, and 2d.

[00028] Fig. 2g is a top schematic view illustrating an embodiment of the J-slots of the drag blocks and the lugs of the tubular support member of the apparatus of Figs. 2, 2a, 2b, 2c, and 2d.

[00029] Fig. 2h is a top schematic view illustrating an embodiment of the J-slots of the drag blocks and the lugs of the tubular support member of the apparatus of Figs. 2, 2a, 2b, 2c, and 2d.

[00030] Fig. 3 is a cross-sectional view illustrating an embodiment of the placement of an apparatus for radially expanding a tubular member within a wellbore casing within a subterranean formation.

[00031] Fig. 3a is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a wellbore casing within a subterranean formation of Fig. 3.

[00032] Fig. 3b is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a wellbore casing within a subterranean formation of Fig. 3.

[00033] Fig. 3c is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a wellbore casing within a subterranean formation of Fig. 3.

[00034] Fig. 3d is a cross-sectional view illustrating an embodiment of the expansion cone support body of the apparatus of Figs. 3, 3a, 3b, and 3c.

[00035] Fig. 3e is a cross-sectional view illustrating an embodiment of the expansion cone support body of Fig. 3d.

[00036] Fig. 3f is a side view illustrating an embodiment of an expansion cone segment for use in the apparatus of Figs. 3, 3a, 3b, and 3c.

[00037] Fig. 3g is a front view illustrating an embodiment of the expansion cone segment of Fig. 3f.

[00038] Fig. 3h is a top view illustrating an embodiment of the expansion cone segment of Fig. 3f.

[00039] Fig. 3i is a top view illustrating an embodiment of interlocking expansion cone segments for use in the apparatus of Figs. 3, 3a, 3b, and 3c.

[00040] Fig. 3j is a top fragmentary circumferential view illustrating an embodiment of the coupling arrangement between the expansion cone segments and the split ring collar for use in the apparatus of Figs. 3, 3a, 3b, and 3c.

[00041] Fig. 4 is a cross-sectional view illustrating an embodiment of the placement of the apparatus of Figs. 3, 3a, 3b, and 3c including an expandable tubular member within an expandable tubular member within a subterranean formation.

[00042] Fig. 4a is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 3, 3a, 3b, and 3c during the expansion of an expandable tubular member within an expandable tubular member within a subterranean formation.

[00043] Fig. 4b is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 3, 3a, 3b, and 3c during the expansion of an expandable tubular member within an expandable tubular member within a subterranean formation.

[00044] Fig. 4c is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 3, 3a, 3b, and 3c during the expansion of an expandable tubular member within an expandable tubular member within a subterranean formation.

[00045] Fig. 4d is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 3, 3a, 3b, and 3c during the expansion of an expandable tubular member within an expandable tubular member within a subterranean formation.

[00046] Fig. 5 is a cross-sectional view illustrating an embodiment of the operation of the apparatus of Figs. 4, 4a, 4b, 4c, and 4d during the radial expansion of the expandable tubular member within the borehole within the subterranean formation.

[00047] Fig. 5a is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 4, 4a, 4b, 4c, and 4d during the radial expansion of the expandable tubular member within the borehole within the subterranean formation.

[00048] Fig. 5b is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 4, 4a, 4b, 4c, and 4d during the radial expansion of the expandable tubular member within the borehole within the subterranean formation.

[00049] Fig. 5c is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 4, 4a, 4b, 4c, and 4d during the radial expansion of the expandable tubular member within the borehole within the subterranean formation.

[00050] Fig. 5d is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 4, 4a, 4b, 4c, and 4d during the radial expansion of the expandable tubular member within the borehole within the subterranean formation.

[00051] Fig. 6 is a cross-sectional view illustrating an embodiment of the placement of an apparatus for radially expanding a tubular member within a borehole within a subterranean formation.



[00052] Fig. 6a is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a borehole within a subterranean formation of Fig. 6.

[00053] Fig. 6b is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a borehole within a subterranean formation of Fig. 6.

[00054] Fig. 6c is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a borehole within a subterranean formation of Fig. 6.

[00055] Fig. 6d is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a borehole within a subterranean formation of Fig. 6.

[00056] Fig. 6e is a cross-sectional view illustrating an embodiment of the expansion cone support body of the apparatus of Figs. 6, 6a, 6b, and 6d.

[00057] Fig. 6f is a cross-sectional view illustrating an embodiment of the expansion cone support body of Fig. 6e.

[00058] Fig. 6g is a side view illustrating an embodiment of an expansion cone segment for use in the apparatus of Figs. 6, 6a, 6b, and 6d.

[00059] Fig. 6h is a front view illustrating an embodiment of the expansion cone segment of Fig. 6g.

[00060] Fig. 6i is a top view illustrating an embodiment of the expansion cone segment of Fig. 6g.

[00061] Fig. 6j is a top view illustrating an embodiment of interlocking expansion cone segments for use in the apparatus of Figs. 6, 6a, 6b, and 6d.

[00062] Fig. 6k is a top fragmentary circumferential view illustrating an embodiment of the coupling arrangement between the expansion cone segments and the split ring collar for use in the apparatus of Figs. 6, 6a, 6b, and 6d.

[00063] Fig. 7 is a cross-sectional view illustrating an embodiment of the placement of the apparatus of Figs. 6, 6a, 6b, and 6d including an expandable tubular member within a borehole within a subterranean formation.

[00064] Fig. 7a is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 6, 6a, 6b, and 6d including an expandable tubular member within a borehole within a subterranean formation.

[00065] Fig. 7b is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 6, 6a, 6b, and 6d including an expandable tubular member within a borehole within a subterranean formation.

[00066] Fig. 7c is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 6, 6a, 6b, and 6d including an expandable tubular member within a borehole within a subterranean formation.

[00067] Fig. 8 is a cross-sectional view illustrating an embodiment of the operation of the apparatus of Figs. 7, 7a, 7b, 7c, and 7d during the radial expansion of the expandable tubular member within a borehole within a subterranean formation.

[00068] Fig. 8a is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 7, 7a, 7b, 7c, and 7d during the radial expansion of the expandable tubular member within a borehole within a subterranean formation.

[00069] Fig. 8b is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 7, 7a, 7b, 7c, and 7d during the radial expansion of the expandable tubular member within a borehole within a subterranean formation.

[00070] Fig. 8c is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 7, 7a, 7b, 7c, and 7d during the radial expansion of the expandable tubular member within a

borehole within a subterranean formation.

[00071] Fig. 8d is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 7, 7a, 7b, 7c, and 7d during the radial expansion of the expandable tubular member within a borehole within a subterranean formation.

[00072] Fig. 9 is a fragmentary cross sectional view illustrating an embodiment of an expansion cone assembly in an unexpanded position.

[00073] Fig. 9a is a cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 9.

[00074] Fig. 10 is a fragmentary cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 9 in an expanded position.

[00075] Fig. 10a is a cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 10.

[00076] Fig. 11 is a fragmentary cross sectional view illustrating an embodiment of an expansion cone assembly in an unexpanded position.

[00077] Fig. 11a is a cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 11.

[00078] Fig. 12 is a fragmentary cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 11 in an expanded position.

[00079] Fig. 12a is a cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 12.

[00080] Fig. 13 is a fragmentary cross sectional view illustrating an embodiment of an expansion cone assembly in an unexpanded position.

[00081] Fig. 13a is a cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 13.

[00082] Fig. 13b is a fragmentary top circumferential view illustrating an embodiment of the expansion cone segment assembly of Fig. 13 that illustrates the interleaved sets of collets.

[00083] Fig. 13c is a fragmentary cross sectional view illustrating an embodiment of the interleaved collets of Fig. 13b.

[00084] Fig. 14 is a fragmentary cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 13 in an expanded position.

[00085] Fig. 14a is a cross sectional view illustrating an embodiment of the expansion cone assembly of Fig. 14.

[00086] Fig. 15 is a cross-sectional view illustrating an embodiment of the placement of an apparatus for radially expanding a tubular member within a borehole within a subterranean formation.

[00087] Fig. 15a is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a borehole within a subterranean formation of Fig. 15.

[00088] Fig. 15b is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a borehole within a subterranean formation of Fig. 15.

[00089] Fig. 15c is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus for radially expanding a tubular member within a borehole within a subterranean formation of Fig. 15.

[00090] Fig. 15d is a cross-sectional view illustrating an embodiment of the expansion cone support body of the apparatus of Figs. 15, 15a, 15b, and 15c.

[00091] Fig. 15e is a cross-sectional view illustrating an embodiment of the expansion cone support body of Fig. 15d.

[00092] Fig. 15f is a side view illustrating an embodiment of an expansion cone segment for use in the apparatus of Figs. 15, 15a, 15b, and 15c.

[00093] Fig. 15g is a front view illustrating an embodiment of the expansion cone segment of Fig. 15f.

[00094] Fig. 15h is a top view illustrating an embodiment of the expansion cone segment of Fig. 15f.

[00095] Fig. 15i is a top view illustrating an embodiment of interlocking expansion cone segments for use in the apparatus of Figs. 15, 15a, 15b, and 15c.

[00096] Fig. 15j is a top fragmentary circumferential view illustrating an embodiment of the coupling arrangement between the expansion cone segments and the split ring collar for use in the apparatus of Figs. 15, 15a, 15b, and 15c.

[00097] Fig. 16 is a cross-sectional view illustrating an embodiment of the placement of the apparatus of Figs. 15, 15a, 15b, 15c, 15d, 15e, 15f, 15g, 15h, 15i, and 15j including an expandable tubular member within a borehole within a subterranean formation.

[00098] Fig. 16a is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 15, 15a, 15b, 15c, 15d, 15e, 15f, 15g, 15h, 15i, and 15j including an expandable tubular member within a borehole within a subterranean formation.

[00099] Fig. 16b is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 15, 15a, 15b, 15c, 15d, 15e, 15f, 15g, 15h, 15i, and 15j including an expandable tubular member within a borehole within a subterranean formation.

[00100] Fig. 16c is a fragmentary cross-sectional view illustrating an embodiment of the placement of a section of the apparatus of Figs. 15, 15a, 15b, 15c, 15d, 15e, 15f, 15g, 15h, 15i, and 15j including an expandable tubular member within a borehole within a subterranean formation.

[00101] Fig. 17 is a cross-sectional view illustrating an embodiment of the operation of the apparatus of Figs. 16, 16a, 16b, and 16c during the radial expansion of the expandable tubular member within a borehole within a subterranean formation.

[00102] Fig. 17a is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 16, 16a, 16b, and 16c during the radial expansion of the expandable tubular member within a borehole within a subterranean formation.

[00103] Fig. 17b is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 16, 16a, 16b, and 16c during the radial expansion of the expandable tubular member within a borehole within a subterranean formation.

[00104] Fig. 17c is a fragmentary cross-sectional view illustrating an embodiment of the operation of a section of the apparatus of Figs. 16, 16a, 16b, and 16c during the radial expansion of the expandable tubular member within a borehole within a subterranean formation.

[00105] Fig. 18a is a cross sectional view illustrating an embodiment of a segmented expansion cone assembly in an unexpanded position.

[00106] Fig. 18b is a fragmentary circumferential top view illustrating an embodiment of the expansion cone and split ring collar of Fig. 18a.

[00107] Fig. 18c is a fragmentary cross-sectional view illustrating an embodiment of the expansion cone support flange of the expansion cone assembly of Fig. 18a.

[00108] Fig. 18d is a cross-sectional view illustrating an embodiment of the expansion cone support flange of Fig. 18c.

[00109] Fig. 19a is a cross sectional view illustrating an embodiment of the segmented expansion cone assembly of Fig. 18a in an expanded position.

[00110] Fig. 19b is a fragmentary circumferential top view illustrating an embodiment of the expansion cone

of Fig. 19a.

[000111] Fig. 20a is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000112] Fig. 20b is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000113] Fig. 20c is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000114] Fig. 20d is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000115] Fig. 20e is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000116] Fig. 20f is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000117] Fig. 20g is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000118] Fig. 20h is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000119] Fig. 20i is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000120] Fig. 20j is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000121] Fig. 20k is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000122] Fig. 20l is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000123] Fig. 20m is a top circumferential view illustrating an embodiment of an interlocking expansion cone segment geometry.

[000124] Fig. 21a is a fragmentary cross sectional view illustrating an embodiment of a system for radially expanding a tubular member in a first direction.

[000125] Fig. 21b is a fragmentary cross sectional view illustrating an embodiment of a system for radially expanding a tubular member in a second direction.

[000126] Fig. 22a is a side view illustrating an embodiment of the operation of the system of Figs. 21a and 21b.

[000127] Fig. 22b is a side view illustrating an embodiment of the operation of the system of Figs. 21a and 21b.

[000128] Fig. 23a is cross sectional view illustrating an embodiment of the system of Fig. 22a.

[000129] Fig. 23b is cross sectional view illustrating an embodiment of the system of Fig. 22b.

[000130] Fig. 24 is a schematic view illustrating an embodiment of an expansion device used with the system of Figs. 21a and 21b.

[000131] Fig. 25a is a fragmentary cross sectional view illustrating an embodiment of the operation of the system of Figs. 21a and 21b.

[000132] Fig. 25b is a fragmentary cross sectional view illustrating an embodiment of the operation of the system of Figs. 21a and 21b.



- [000133] Fig. 25c is a fragmentary cross sectional view illustrating an embodiment of the operation of the system of Figs. 21a and 21b.
- [000134] Fig. 26a is a side view illustrating an embodiment of a system for radially expanding a tubular member.
- [000135] Fig. 26b is a cross sectional view illustrating an embodiment of the operation of the system for radially expanding a tubular member of Fig. 26a.
- [000136] Fig. 27a is a cross sectional view illustrating an embodiment of the system of Figs. 26a.
- [000137] Fig. 27b is a cross sectional view illustrating an embodiment of the system of Figs. 26b.
- [000138] Fig. 28 is a side view illustrating an embodiment of a system for radially expanding a tubular member.
- [000139] Fig. 28a is a side view illustrating an embodiment of the system for radially expanding a tubular member illustrated in Fig. 28.
- [000140] Fig. 29a is a cross sectional view illustrating an embodiment of the system illustrated in Fig. 28.
- [000141] Fig. 29b is a cross sectional view illustrating an embodiment of the system illustrated in Fig. 28.
- [000142] Fig. 29c is a cross sectional view illustrating an embodiment of the system illustrated in Fig. 28 in operation.
- [000143] Fig. 29d is a cross sectional view illustrating an embodiment of the system illustrated in Fig. 28 in operation.
- [000144] Fig. 29e is a top view illustrating an embodiment of the system illustrated in Fig. 28.
- [000145] Fig. 30a is a side view illustrating an embodiment of a system for radially expanding a tubular member.
- [000146] Fig. 30b is a side view illustrating an embodiment of the operation of the system of Fig. 30a for radially expanding a tubular member.
- [000147] Fig. 30c is a cross sectional view illustrating an embodiment of a system of Fig. 30a for radially expanding a tubular member.
- [000148] Fig. 30d is a cross sectional view illustrating an embodiment of the operation of the system of Fig. 30b for radially expanding a tubular member.
- [000149] Fig. 31a is a side view illustrating an embodiment of a system for radially expanding a tubular member.
- [000150] Fig. 31b is a side view illustrating an embodiment of the operation of the system of Fig. 31a for radially expanding a tubular member.
- [000151] Fig. 32 is a fragmentary cross sectional view illustrating an embodiment of a system for radially expanding a tubular member.
- [000152] Fig. 33a is a fragmentary cross sectional view illustrating an embodiment of a system for radially expanding a tubular member.
- [000153] Fig. 33b is a fragmentary cross sectional view illustrating an embodiment of the operation of the system of Fig. 33a for radially expanding a tubular member.
- [000154] Fig. 34a is a side view illustrating an embodiment of a system for radially expanding a tubular member.
- [000155] Fig. 34b is a side view illustrating an embodiment of the operation of the system for radially expanding a tubular member of Fig. 34a.
- [000156] Fig. 34c is a cross sectional view illustrating an embodiment of a system of Fig. 34a for radially

expanding a tubular member.

[000157] Fig. 34d is a cross sectional view illustrating an embodiment of the operation of the system for radially expanding a tubular member of Fig. 34b.

[000158] Fig. 35a is a side view illustrating an embodiment of a system for radially expanding a tubular member.

[000159] Fig. 35b is a side view illustrating an embodiment of the operation of the system for radially expanding a tubular member of Fig. 35a.

[000160] Fig. 35c is a cross sectional view illustrating an embodiment of a system for radially expanding a tubular member of Fig. 35a.

[000161] Fig. 35d is a cross sectional view illustrating an embodiment of the operation of the system for radially expanding a tubular member of Fig. 35b.

[000162] Fig. 36a is a side view illustrating an embodiment of a system for radially expanding a tubular member.

[000163] Fig. 36b is a side view illustrating an embodiment of the operation of the system for radially expanding a tubular member of Fig. 36a.

[000164] Fig. 37a is a side view illustrating an embodiment of a system for radially expanding a tubular member.

[000165] Fig. 37b is a cross sectional view illustrating an embodiment of the system for radially expanding a tubular member of Fig. 37a.

[000166] Fig. 38a is a side view illustrating an embodiment of the operation of the system for radially expanding a tubular member of Fig. 37a.

[000167] Fig. 38b is a cross sectional view illustrating an embodiment of the operation of the system for radially expanding a tubular member of Fig. 37b.

[000168] Fig. 39a is an exploded view illustrating an exemplary embodiment of a system for radially expanding a tubular member.

[000169] Fig. 39b is a cross-sectional view illustrating an exemplary embodiment of the system for radially expanding a tubular member of Fig. 39a.

[000170] Fig. 39c is a cross-sectional view illustrating an exemplary embodiment of the system for radially expanding a tubular member of Fig. 39a.

[000171] Fig. 40a is a cross-sectional view illustrating an exemplary embodiment of a system for radially expanding a tubular member.

[000172] Fig. 40b is a cross-sectional view illustrating an exemplary embodiment of the operation of the system for radially expanding a tubular member of Fig. 40a.

[000173] Fig. 40c is a cross-sectional view illustrating an exemplary embodiment of couplers on the system for radially expanding a tubular member of Fig. 40a.

[000174] Fig. 41a is a cross-sectional view illustrating an exemplary embodiment of a system for radially expanding a tubular member including a laser cladded coating.

[000175] Fig. 41b is a cross-sectional view illustrating an exemplary embodiment of the system for radially expanding a tubular member including a non-uniform laser cladded coating.

[000176] Fig. 42a is a cross-sectional view illustrating an exemplary embodiment of the system for radially expanding a tubular member of Fig. 41a including a diamond coating.

[000177] Fig. 42b is a cross-sectional view illustrating an exemplary embodiment of the system for radially expanding a tubular member of Fig. 41b including a diamond coating.

#### Detailed Description of the Illustrative Embodiments

[000178] Referring initially to Figs. 1, 1a, 1b, 1c, and 1d, an embodiment of an apparatus and method for radially expanding a tubular member will now be described. As illustrated in Figs. 1 and 1a-1d, a wellbore 100 is positioned in a subterranean formation 105. In an exemplary embodiment, the wellbore 100 may include a pre-existing cased section 110. The wellbore 100 may be positioned in any orientation from vertical to horizontal.

[000179] In order to extend the wellbore 100 into the subterranean formation 105, a drill string is used in a well known manner to drill out material from the subterranean formation 105 to form a new wellbore section 115. In a preferred embodiment, the inside diameter of the new wellbore section 115 is greater than or equal to the inside diameter of the preexisting wellbore casing 110.

[000180] A tubular member 120 defining a passage 120a may then be positioned within the wellbore section 115 with an upper end 120b of the tubular member 120 coupled to the wellbore casing 110 and a lower end 120c of the tubular member 120 extending into the wellbore section 115. The tubular member 120 may be positioned within the wellbore section 115 and coupled to the wellbore casing 110 in a conventional manner. In a preferred embodiment, the tubular member 120 is positioned within the wellbore section 115 and coupled to the wellbore casing 110 using one or more of the methods and apparatus disclosed in one or more of the following (1) U.S. patent application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, (3) U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, (4) U.S. patent application serial no. 09/440,338, attorney docket no. 25791.9.02, filed on 11/15/1999, (5) U.S. patent application serial no. 09/523,460, attorney docket no. 25791.11.02, filed on 3/10/2000, (6) U.S. patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, (7) U.S. patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, (8) U.S. patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, (9) U.S. patent application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, (10) PCT patent application serial no. PCT/US00/18635, attorney docket no. 25791.25.02, filed on 7/9/2000, (11) U.S. provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (12) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (13) U.S. provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (14) U.S. provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (15) U.S. provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (16) U.S. provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (17) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (18) U.S. provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (19) U.S. provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (20) U.S. provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (21) U.S. provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (22) U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001; and (23) U.S. provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001; and (24) U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, the disclosures of which are incorporated herein by reference.

[000181] As illustrated in Figs. 1 and 1a-1d, an apparatus 200 for radially expanding a tubular member may then be positioned in the new section 115 of the wellbore 100 within the tubular member 120. The apparatus 200 includes a tubular support member 205 defining an internal passage 205a that is coupled to an end of a tubular coupling 210 defining an internal passage 210a. The other end of the tubular coupling 210 is coupled to an end of a tubular support member 215 defining an internal passage 215a that includes a first lug 215b, a radial passage 215c, a first flange 215d, a second flange 215e, a second lug 215f, and an expansion cone support body 215g. The other end of the tubular support member 215 is coupled to a tubular end stop 220 that defines a passage 220a.

[000182] As illustrated in Figs. 1e and 1f, the expansion cone support body 215g includes a first end 215ga, a tapered hexagonal portion 215gb that includes a plurality of T-shaped slots 215gba provided on each of the external faceted surfaces of the tapered hexagonal portion 215gb, and a second end 215gc. In an exemplary embodiment, the angle of attack of the tapered hexagonal portion 215gb ranges from about 35 to 50 degrees for reasons to be described.

[000183] As illustrated in Figs. 1, 1a, 1b, 1c, 1d, 1g, 1h, and 1i, a plurality of expansion cone segments 225 are provided with each including a first end 225a that includes a T-shaped retaining member 225aa, a second end 225b that includes a T-shaped retaining member 225ba that is operable to mate with and be received within corresponding T-shaped slots 215gba on the tapered hexagonal portion 215gb of the expansion cone support body 215g, a first external surface 225bb, a second external surface 225bc, and a third external surface 225bd. In an exemplary embodiment, a total of six expansion cone segments 225 are provided that are slidably coupled to corresponding sides of the tapered hexagonal portion 215gb of the expansion cone support body 215g.

[000184] In an exemplary embodiment, the width of the first external surface 225bb of each expansion cone segment 225 increases in the direction of the second external surface 225bc, the width of the second external surface 225bc is substantially constant, and the width of the third external surface 225bd decreases in the direction of the first end 225a of each expansion cone segment 225 for reasons to be described. In an exemplary embodiment, the first external surface 225bb of each expansion cone segment 225 tapers upwardly in the direction of the second external surface 225bc, the second external surface 225bc tapers upwardly in the direction of the third external surface 225bd, and the third external surface 225bd tapers downwardly in the direction of the first end 225a of each expansion cone segment 225 for reasons to be described. In an exemplary embodiment, the angle of attack of the taper of the first external surface 225bb of each expansion cone segment 225 is greater than the angle of attack of the taper of the second external surface 225bc. In an exemplary embodiment, the first external surface 225bb and second external surface 225bc of each expansion cone segment 225 are arcuate such that when the plurality of expansion cone segment 225 are displaced in the direction of the end stop 220, the first external surfaces 225bb and second external surfaces 225bc of the plurality of expansion cone segments 225 provide a substantially continuous outer circumferential surface for reasons to be described.

[000185] As illustrated in Fig. 1j, in an exemplary embodiment, the external surfaces 225bb, 225bc, and 225bd, of the second ends 225b of the plurality of expansion cone segments 225 are adapted to mate with each other in order to interlock adjacent expansion cone segments 225.

[000186] As illustrated in Figs. 1, 1a, 1b, 1c, 1d, and 1k, a split ring collar 230 defines a passage 230a for receiving the tubular support member 215 and includes a first end with a plurality of T-shaped slots 230b for receiving and mating with corresponding T-shaped retaining members 225aa of the plurality of expansion cone segments 225 and a second end that includes an L-shaped retaining member 230c. In an exemplary embodiment,



the split ring collar 230 is a conventional split ring collar commercially available from Halliburton Energy Services modified in accordance with the teachings of the present disclosure.

[000187] As illustrated in Figs. 1, 1a, 1b, 1c, 1d, and 1m, a drag block assembly 235 that defines a passage 235a for receiving the tubular support member 215 is provided that includes a first end that includes an L-shaped slot 235b for receiving and mating with the L-shaped retaining member 230c of the split ring collar 230, one or more conventional drag block elements 235c, and a J-shaped slot 235d including a retaining slot 235da for receiving the second lug 215f of the tubular support member 215. In an exemplary embodiment, the longitudinal axis of the J-shaped slot 235d of the drag block assembly 235 is substantially parallel to the longitudinal axis of the tubular support member 215 for reasons to be described.

[000188] A first conventional packer cup assembly 240 that defines a passage 240a for receiving the tubular support member 215 includes a first end 240b that mates with the second flange 215e of the tubular support member 215, a conventional sealing cup 240c, and a second end 240d. A tubular spacer 245 that defines a passage 245a for receiving the tubular support member 215 includes a first end 245b that mates with the second end 240c of the first packer cup assembly 240 and a second end 245c. A second conventional packer cup assembly 250 that defines a passage 250a for receiving the tubular support member 215 includes a first end 250b that mates with the second end 245c of the spacer 245, a conventional sealing cup 250c, and a second end 250d that mates with the first flange 215d of the tubular support member 215.

[000189] As illustrated in Figs. 1, 1a, 1b, 1c, 1d, and 1l, a drag block assembly 255 that defines a passage 255a for receiving the tubular support member 215 is provided that includes a first end that includes sealing members, 255b and 255c, one or more conventional drag block elements 255d, and a J-shaped slot 255e including a retaining slot 255ea for receiving the first lug 215b of the tubular support member 215. In an exemplary embodiment, the longitudinal axis of the J-shaped slot 255e of the drag block assembly 255 is substantially parallel to the longitudinal axis of the tubular support member 215 for reasons to be described.

[000190] In an exemplary embodiment, during operation of the apparatus 200, as illustrated in Figs. 1 and 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h, 1i, 1j, 1k, 1l, and 1m, the apparatus may be positioned in the wellbore 115, within the tubular member 120, with the first and second lugs, 215b and 215f, respectively, positioned within the retaining slots, 255ea and 235da, respectively, of the J-slots, 255e and 235da, respectively, of the drag block assembly 255 and 235, respectively. In this manner, the drag block assembly 235 is maintained in a substantially stationary position relative to the tubular support member 215 thereby preventing the expansion cone segments 225 from being displaced downwardly in the longitudinal direction relative to the tubular support member 215 towards the end stop 220. Furthermore, in this manner, the drag block assembly 255 is also maintained in a substantially stationary position relative to the tubular support member 215 thereby preventing the drag block assembly 255 from sealing off the radial passage 215c. In an exemplary embodiment, during the placement of the apparatus 200 within the wellbore 115 and the tubular member 120, the radial passage 215c permits fluidic materials outside of the tubular support member 215 to pass into the passage 215a thereby minimizing overpressure conditions within the annulus outside of the tubular support member 215.

[000191] In an exemplary embodiment, the apparatus 200 is positioned within the expandable tubular member 120 such that the expansion cone body 215g, the end stop 220, and the expansion cone segments 225 extend out of the expandable tubular member 120. In this manner, the plurality of expansion cone segments 225 may be driven up the tapered hexagonal portion 215gb of the expansion cone body 215g without engaging the expandable tubular member 120.

[000192] The tubular support member 215 may then be rotated relative to the drag block assemblies, 235 and 255, thereby displacing the lugs, 215f and 215b, respectively, with respect to the J-shaped slots, 235d and 255e, respectively. The tubular support member 215 may then be displaced in an upward longitudinal direction relative to the drag block assemblies 235 and 255 which is towards the tubular end stop 220 and which results in the drag block assemblies 235 and 255 being displaced in a downward longitudinal direction relative to the tubular support member 215. During the upward longitudinal displacement of the tubular support member 215 relative to the drag block assemblies 235 and 255, the drag block assemblies 235 and 255 are maintained in a substantially stationary position with respect to the expandable tubular member 120 by the frictional forces exerted by the drag blocks 235c and 255d of the drag block assemblies 235 and 255, respectively, on the expandable tubular member 120. During the upward longitudinal displacement of the tubular support member 215 relative to the drag block assemblies 235 and 255, the lugs 215f and 215b are guided in a substantially longitudinal direction by the J-slots 235d and 255e, respectively, of the drag block assemblies 235 and 255.

[000193] The downward longitudinal displacement of the drag block assembly 235 relative to the tubular support member 215 displaces the split ring collar 230 along with the expansion cone segments 225. As a result, the expansion cone segments 225 are driven up the tapered hexagonal portion 215gb of the expansion cone support body 215g until the end faces of the plurality of expansion cone segments 225 impact the stop member 220 which increases the outside diameter of the portion of the apparatus 200 defined by the plurality of expansion cone segments 225. In an exemplary embodiment, once the expansion cone segments 225 impact the stop member 220, the outer surfaces 225bb and 225bc of the plurality of expansion cone segments 225 provide a substantially continuous outer surface in the circumferential direction having a diameter that is greater than the inside diameter of the expandable tubular member 120. The downward longitudinal displacement of the drag block assembly 255 relative to the tubular support member 215 seals off the radial passage 215c thereby preventing the pressurized fluidic material 275 from entering the annulus surrounding the tubular support member 215 through the radial passage 215c.

[000194] In an exemplary embodiment, as illustrated in Figs. 2, 2a, 2b, 2c, 2d, 2e, and 2f, the expandable tubular member 120 may then be radially expanded using the apparatus 200 by injecting a fluidic material 275 through the passages 205a, 210a, and 215a. The injection of the fluidic material 275 pressurizes the interior 120a of the expandable tubular member 120. In addition, the packer cup assemblies 240 and 250 seal off an annular region 120aa adjacent the packer cup assemblies 240 and 250 which is located between the expandable tubular member 120 and the tubular support member 215, resulting in the injection of the fluidic material 275 pressurizing the annular region 120aa.

[000195] The injection of the fluidic material 275 also pressurizes the interior 120a of the expandable tubular member 120 thereby plastically deforming and radially expanding the expandable tubular member 120 off of the expansion cone segments 225. Because the external surfaces 225bb and 225bc of the plurality of expansion cone segments 225 are tapered, the plastic deformation and radial expansion of the expandable tubular member 120 proximate the plurality of expansion cone segments 225 is facilitated. Furthermore, in an exemplary embodiment, the injection of the fluidic material 275 also pressurizes the annular region 120aa defined between the interior surface of the expandable tubular member 120 and the exterior surface of the tubular support member 215 that is bounded on the upper end by the packer cup assembly 240 and on the lower end by the plurality of expansion cone segments 225. Furthermore, in an exemplary embodiment, the pressurization of the annular region 120aa also radially expands the surrounding portion of the expandable tubular member 120. In this manner, the plastic

deformation and radial expansion of the expandable tubular member 120 is enhanced. Furthermore, during operation of the apparatus 200, the packer cup assemblies 240 and 250 prevent the pressurized fluidic material 275 from passing above and beyond the packer cup assemblies 240 and 250 and thereby define the length of the pressurized annular region 120aa. In an exemplary embodiment, the pressurization of the annular region 120aa decreases the operating pressures required for plastic deformation and radial expansion of the expandable tubular member 120 by as much as 50% and also reduces the angle of attack of the tapered external surfaces 225bb and 225bc of the expansion cone segments 225.

[000196] The radial expansion of the expandable tubular member 120 may then continue until the upper end 120b of the expandable tubular member is radially expanded and plastically deformed along with the overlapping portion of the wellbore casing 110. Because the plurality of expansion cone segments 225 may be adjustably positioned from an outside diameter less than the inside diameter of the expandable tubular member 120 to an outside diameter substantially equal to the inside diameter of the pre-existing casing 110, the resulting wellbore casing, including the casing 110 and the radially expanded tubular member 120, created by the operation of the apparatus 200 may have a single substantially constant inside diameter thereby providing a mono-diameter wellbore casing.

[000197] If the expansion cone segments 225 become lodged within the tubular member 120 during the radial expansion process, the tubular support member 215 may be displaced in the downward longitudinal direction and then rotated relative to the drag block assemblies 235 and 255, thereby positioning the lugs 215b and 215f, respectively, within the retaining slots, 255ea and 235da, respectively, of the J-slots, 255e and 235d, respectively. As a result, the expansion cone segments 225 will be displaced down the tapered hexagonal portion 215gb of the expansion cone support body 215g and away from the end stop 220 thereby decreasing the outside diameter of the portion of the apparatus 200 defined by the plurality of expansion cone segments 225. In this manner, the tubular support member 205, the tubular support member 210, the tubular support member 215, the end stop 220, the expansion cone segments 225, the split ring collar 230, the drag block assembly 235, the pack cup assembly 240, the spacer 245, the packer cup assembly 250, and the drag block assembly 255 may then be removed from the tubular member 120.

[000198] During the radial expansion process, the expansion cone segments 225 may be raised out of the expanded portion of the tubular member 120 by applying an axial force to the tubular support member 215. In a preferred embodiment, during the radial expansion process, the expansion cone segments 225 are raised at approximately the same rate as the tubular member 120 is expanded in order to keep the tubular member 120 stationary relative to the new wellbore section 115. In an alternative preferred embodiment, the expansion cone segments 225 are maintained in a stationary position during the radial expansion process thereby allowing the tubular member 120 to be radially expanded and plastically deformed off of the expansion cone segments 225 and into the new wellbore section 115 under the force of gravity and the operating pressure of the interior of the tubular member 120.

[000199] In a preferred embodiment, when the upper end portion of the expandable tubular member 120 and the lower portion of the wellbore casing 110 which overlap with each other are plastically deformed and radially expanded by the expansion cone segments 225, the expansion cone segments 225 are displaced out of the wellbore 100 by both the operating pressure within the interior of the tubular member 120 and a upwardly directed axial force applied to the tubular support member 205.

[000200] In a preferred embodiment, the operating pressure and flow rate of the fluidic material 275 is controllably ramped down when the expansion cone segments 225 reach the upper end portion of the expandable tubular member 120. In this manner, the sudden release of pressure caused by the complete radial expansion and plastic deformation of the expandable tubular member 120 off of the expansion cone segments 225 can be minimized. In a preferred embodiment, the operating pressure is reduced in a substantially linear fashion from 100% to about 10% during the end of the extrusion process beginning when the expansion cone segments 225 are within approximately 5 feet from completion of the extrusion process.

[000201] Alternatively, or in combination, the wall thickness of the upper end portion of the expandable tubular member 120 is tapered in order to gradually reduce the required operating pressure for plastically deforming and radially expanding the upper end portion of the tubular member 120. In this manner, shock loading of the apparatus 200 is reduced.

[000202] Alternatively, or in combination, a shock absorber is provided in the tubular support member 205 in order to absorb the shock caused by the sudden release of pressure. The shock absorber may comprise, for example, any conventional commercially available shock absorber, bumper sub, or jars adapted for use in wellbore operations.

[000203] Alternatively, or in combination, an expansion cone catching structure is provided in the upper end portion of the expandable tubular member 120 in order to catch or at least decelerate the expansion cone segments 225.

[000204] Alternatively, or in combination, during the radial expansion process, an upward axial force is applied to the tubular support member 215 sufficient to plastically deform and radially expand the tubular member 120 off of the external surfaces 225bb and 225bc of the plurality of expansion cone segments 225.

[000205] Alternatively, or in combination, in order to facilitate the pressurization of the interior 120a of the expandable tubular member 120 by the injection of the fluidic materials 275, the region within the wellbore section 115 below the apparatus 200 may be fluidically sealed off in a convention manner using, for example, a packer.

[000206] Once the radial expansion process is completed, the tubular support member 205, the tubular support member 210, the tubular support member 215, the end stop 220, the expansion cone segments 225, the split ring collar 230, the drag block assembly 235, the pack cup assembly 240, the spacer 245, the packer cup assembly 250, and the drag block assembly 255 are removed from the wellbore 100.

[000207] In an alternative embodiment, as illustrated in Figs. 2h and 2i, the J-slots 235d and 255e include one or more intermediate retaining slots, 235db and 255eb, respectively, that permit the relative longitudinal displacement of the tubular support member 215 relative to the drag block assemblies 235 and 255, respectively, to be set at one or more intermediate stop positions. In this manner, the plurality of expansion segments 225 may be positioned at one or more intermediate positions on the tapered hexagonal portion 215gb of the expansion cone support body 215g thereby permitting the outside diameter of the apparatus 200 defined by the expansion cone segments 225 to be adjusted to one or more intermediate sizes. In this manner, the radial expansion and plastic deformation of the expandable tubular member 120 be provided in different operation stages, each having a different expansion diameter. Furthermore, if the plurality of expansion cone segments 225 become lodged within the expandable tubular member 120, then the position of the plurality of expansion cone segments 225 may be adjusted to provide a smaller outside diameter of the apparatus 200 and the radial expansion process may be continued by injecting the fluidic material 275 and/or applying an upward axial force to the tubular support member 215.



[000208] Referring to Figs. 3, 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, and 3j, an alternative embodiment of an apparatus 300 for forming a wellbore casing in a subterranean formation will now be described. The apparatus 300 includes a tubular support member 305 defining an internal passage 305a that is coupled to an end of a tubular coupling 310 defining an internal passage 310a. The other end of the tubular coupling 310 is coupled to an end of a tubular support member 315 defining an internal passage 315a that includes a first flange 315b having oppositely tapered end-walls, 315ba and 315bb, a second flange 315c, a radial passage 315d, a third flange 315e, a fourth flange 315f, a fifth flange 315g having oppositely tapered end-walls 315ga and 315gb, a fifth flange 315h, and an expansion cone support body 315i. The other end of the tubular support member 315 is coupled to a tubular end stop 320 that defines a passage 320a.

[000209] As illustrated in Figs. 3d and 3e, the expansion cone support body 315i includes a first end 315ia, a tapered hexagonal portion 315ib that includes a plurality of T-shaped slots 315iba provided on each of the external faceted surfaces of the tapered hexagonal portion 315ib, and a second end 315ic. In an exemplary embodiment, the angle of attack of the tapered hexagonal portion 315ib ranges from about 35 to 50 degrees for reasons to be described.

[000210] As illustrated in Figs. 3, 3a, 3b, 3c, 3d, 3e, 3f, 3g, and 3h, a plurality of expansion cone segments 325 are provided with each including a first end 325a that includes T-shaped retaining member 325aa, a second end 325b that includes a T-shaped retaining member 325ba that is operable to mate with and be received within corresponding T-shaped slots 315iba on the tapered hexagonal portion 315ib of the expansion cone support body 315i, a first external surface 325bb, a second external surface 325bc, and a third external surface 325bd. In an exemplary embodiment, a total of six expansion cone segments 325 are provided that are slidably coupled to corresponding sides of the tapered hexagonal portion 315ib of the expansion cone support body 315i.

[000211] In an exemplary embodiment, the width of the first external surface 325bb of each expansion cone segments 325 increases in the direction of the second external surface 325bc, the width of the second external surface 325bc is substantially constant, and the width of the third external surface 325bd decreases in the direction of the first ends 325a of each expansion cone segment 225 for reasons to be described. In an exemplary embodiment, the first external surface 325bb of each expansion cone segment 325 tapers upwardly in the direction of the second external surface 325bc, the second external surface 325bc tapers upwardly in the direction of the third external surface 325bd, and the third external surface 325bd tapers downwardly in the direction of the first end 325a of each expansion cone segment 225 for reasons to be described. In an exemplary embodiment, the angle of attack of the taper of the first external surface 325bb of each expansion cone segment 325 is greater than the angle of attack of the taper of the second external surface 325bc. In an exemplary embodiment, the first external surface 325bb and the second external surface 325bc of each expansion cone segment 325 are arcuate such that when the plurality of expansion cone segments 325 are displaced in the direction of the end stop 320, the first external surface 325bb and the second external surface 325bc of the plurality of expansion cone segments 325 provide a substantially continuous outer circumferential surface for reasons to be described.

[000212] As illustrated in Fig. 3i, in an exemplary embodiment, the external surfaces 325bb, 325bc, and 325bd, of the second ends 325b of the plurality of expansion cone segments 325 are adapted to mate with each other in order to interlock adjacent expansion cone segments 325.

[000213] As illustrated in Fig. 3h, 3i, and 3j, a split ring collar 330 that defines a passage 330a for receiving the tubular support member 315 and includes a first end with a plurality of T-shaped slots 330b for receiving and mating with corresponding T-shaped retaining members 325aa of the plurality of expansion cone segments 325 and

a second end that includes an L-shaped retaining member 330c. In an exemplary embodiment, the split ring collar 330 is a conventional split ring collar commercially available from Halliburton Energy Services modified in accordance with the teachings of the present disclosure.

[000214] As illustrated in Fig. 3, 3b and 3c, a collet assembly 335 is provided that includes a support ring 335a that defines a passage 335aa for receiving the tubular support member 315 and is coupled to an end of a resilient collet 335b positioned proximate the fourth flange 315g of the tubular support member 315. Resilient collet 335b includes an upper set of tapered shoulders 335ba and 335bb and a lower set of tapered shoulders 335bc and 335bd which are positioned opposite the upper set of tapered shoulders 335ba and 335bb. The other end of the collet 335b is coupled to an end of a tubular sleeve 335c that defines a passage 335ca. The other end of the tubular sleeve 335c is coupled to an end of a pin 335d. The other end of the pin 335d is coupled to a ring 335e that defines a passage 335ea for receiving the fifth flange 315h of the tubular support member 315. An end of a tubular coupling sleeve 335f that defines a passage 335fa for receiving the tubular support member 315 is received within the opening 335ca of the tubular sleeve 335c that includes a recess 335fb for receiving the fifth flange 315h of the tubular support member 315 and the ring 335e, and a radial passage 335fc for receiving the pin 335d. Another end of the tubular coupling sleeve 335f includes a passage 335fd for receiving the tubular support member 315 and a slot 335fe for receiving the L-shaped retaining member 330c of the split ring collar 330. A ring 335g that defines a passage 335ga for receiving the tubular support member 315, a spring 335h, and a ring 335i that defines a passage 335ia for receiving the tubular support member 315 are also received within the recess 335fb. The ring 335g is positioned proximate one end of the recess 335fb, the ring 335i is positioned proximate the fifth flange 315h of the tubular support member 315 within the other end of the recess 335fb and the spring 335h is positioned between the rings 335g and 335i.

[000215] A first conventional packer cup assembly 340 that defines a passage 340a for receiving the tubular support member 315 includes a first end 340b that mates with the fourth flange 315f of the tubular support member 315, a conventional sealing cup 340c, and a second end 340d. A tubular spacer 345 that defines a passage 345a for receiving the tubular support member 315 includes a first end 345b that mates with the second end 340d of the first packer cup assembly 340 and a second end 345c. A second conventional packer cup assembly 350 that defines a passage 350a for receiving the tubular support member 315 includes a first end 350b that mates with the second end 345c of the spacer 345, a conventional sealing cup 350c, and a second end 350d that mates with the third flange 315e of the tubular support member 315.

[000216] As illustrated in Figs. 3, 3a, and 3b, a collet assembly 355 is provided that includes a support ring 355a that defines a passage 355aa for receiving the tubular support member 315 and is coupled to an end of a resilient collet 355b which is positioned proximate the first flange 315b of the tubular support member 315. Resilient collet 355b includes a set of upper tapered shoulders 355ba and 355bb, and a set of lower tapered shoulders 355bc and 355bd, respectively, positioned opposite the set of upper tapered shoulders 355ba and 355bb. The other end of the collet 355b is coupled to an end of a tubular sleeve 355c that defines a passage 355ca. The other end of the tubular sleeve 355c is coupled to an end of a pin 355d. The other end of the pin 355d is coupled to a ring 355e that defines a passage 355ea for receiving the second flange 315c of the tubular support member 315. An end of a tubular sleeve 355f that defines a passage 355fa for receiving the tubular support member 315 is received within the opening 355ca of the tubular sleeve 355c that includes a recess 355fb for receiving the second flange 315c of the tubular support member 315 and the ring 355e, and a radial passage 355fc for receiving the pin 355d. Another end of the tubular sleeve 355f includes a passage 355fd for receiving the tubular support member

315, a recess 355fe for receiving an end of the tubular sleeve 355c, and sealing members 355ff. A ring 355g that defines a passage 355ga for receiving the tubular support member 315 and a spring 355h are also received within the recess 355fb. An end of the ring 355g is positioned proximate the second flange 315c of the tubular support member 315 within an end of the recess 355fb and the other end of the ring 355g is positioned adjacent an end of the spring 355h. The other end of the spring 355h is positioned proximate the other end of the recess 355fb.

[000217] In an exemplary embodiment, during operation of the apparatus 300, as illustrated in Figs. 3, 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, and 3j, the apparatus 300 may be initially positioned in the wellbore 100, within the casing 110, with the collet assemblies 335 and 355 positioned in a neutral position in which the radial passage 315d of the tubular support member 315 is not covered by the tubular sleeve 355f and the expansion cone segments 325 are not driven up the tapered hexagonal portion 315ib of the expansion cone support body 315i of the tubular support member 315 and into contact with the stop member 320. In this manner, fluidic materials within the interior 315a of the tubular support member 315 may pass through the radial passage 315d and into the annulus between the apparatus 300 and the casing 110 thereby preventing over pressurization of the annulus. Furthermore, in this manner, the outside diameter of the plurality of expansion cone segments 325 is less than or equal to the outside diameter of the stop member 320 thereby permitting the apparatus 300 to be displaced within the casing 110.

[000218] As illustrated in Figs. 4, 4a, 4b, 4c, and 4d, the apparatus 300 may then be positioned in the tubular member 120. During the insertion of the apparatus into the tubular member 120, the upper end 120b of the tubular member 120 may impact the tapered shoulders 335bb and 355bb of the collets 335b and 355b, respectively, thereby driving the collets 335b and 355b backward until the tapered shoulders 335bd and 355bd are positioned proximate the tapered shoulders 315ga and 315ba, respectively, of the tubular support member 315. As a result, the support rings 335a and 355a, the collets 335b and 355b, the tubular sleeves 335c and 355c, the pins 335d and 355d, the rings 335e and 355e, and the rings 335g and 355g, of the collet assemblies 335 and 355, respectively, are driven backward, compressing the springs 335h and 355h, and applying axial biasing forces to the tubular coupling sleeve 335f and the tubular sleeve 355f, respectively. In this manner, an axial biasing force is applied to the split ring collar 330 and the plurality of expansion cone segments 325 which prevents the plurality of expansion cone segments 325 from being driven up the tapered hexagonal portion 315ib of the expansion cone support body 315i of the tubular support member 315 and into contact with the stop member 320. Thus, the plurality of expansion cone segments 325 are maintained with an outside diameter which is less than the inside diameter of the tubular member 120, thereby permitting the apparatus 300 to be displaced within the tubular member 120. Furthermore, in this manner, an axial biasing force is applied to the tubular sleeve 355f, which prevents the tubular sleeve 355f from covering the radial passage 315d in the tubular support member 315, allowing fluidic materials within the interior 315a of the tubular support member 315 to pass through the radial passage 315d and into the annulus between the apparatus 300 and the tubular member 120, thereby preventing over pressurization of the annulus.

[000219] The apparatus 300 may then be at least partially positioned in the open hole section 115a of the wellbore section 115, beyond the lower end 120c of the tubular member 120. In an exemplary embodiment, that portion of the apparatus 300 that includes the stop member 320, the expansion cone segments 325, the split ring collar 330, the collet assembly 335, the packer cup assembly 340, the spacer 345, the packer cup assembly 350, and the collet assembly 355 is then positioned in the open hole section 115a of the wellbore section 115, beyond the lower end 120 of the tubular member 120 for reasons to be described. Because the collets 335b and 355b are resilient, once the apparatus 300 has been positioned in the open hole section 115a of the wellbore section 115,

beyond the lower end 120c of the tubular member 120, the tapered shoulders 335ba and 355ba of the collets 335b and 355b, respectively, may spring outwardly in the radial direction.

[000220] The apparatus 300 may then be repositioned at least partially back within the tubular member 120. During the re-insertion of the apparatus 300 into the tubular member 120, the lower end 120c of the tubular member 120 may impact the tapered shoulders 335ba and 355ba of the collets 335b and 355b, respectively, thereby driving the collets forward until the tapered shoulders 335bc and 355bc of the collets 335b and 355b, respectively, are positioned proximate the tapered shoulders 315gb and 315bb, respectively, of the tubular support member 315. As a result, the support rings 335a and 355a, the collets 335b and 355b, the tubular sleeves 335c and 355c, the pins 335d and 355d, the rings 335e and 355e, the tubular coupling sleeve 335f, the tubular sleeve 355f, the rings 335g and 355g, and the ring 335i of the collet assemblies 335 and 355, respectively, are driven forward, thereby compressing the springs 335h and 355h, sealing off the radial passage 315d, and driving the plurality of expansion cone segments 325 up the tapered hexagonal portion 315ib of the expansion cone support body 315i of the tubular support member 315 and into contact with the stop member 320.

[000221] As a result, the outside diameter of the plurality of expansion cone segments 325 expands to become greater than the inside diameter of expandable tubular member 120, thereby permitting the apparatus 300 to be used to radially expand and plastically deform the tubular member 120, and fluidic materials within the interior 315a of the tubular support member 315 may no longer pass through the radial passage 315d into the annulus between the apparatus 300 and the tubular member 120, thereby permitting the interior of the apparatus 300 to be pressurized.

[000222] The apparatus 300 may then be operated to radially expand and plastically deform the tubular member 120 by applying an upward axial force to the tubular support member 315 and/or by injecting a pressurized fluidic material into the tubular support member 315.

[000223] In particular, as illustrated in Figs. 5, 5a, 5b, 5c, and 5d, the expandable tubular member 120 may then be radially expanded using the apparatus 300 by injecting a fluidic material 275 into the apparatus through the passages 305a, 310a, 315a, and 320a. The injection of the fluidic material 275 may pressurize the interior 120a of the expandable tubular member 120. In addition, because the packer cup assemblies 340 and 350 seal off an annular region 120aa below the packer cup assemblies 340 and 350 located between the expandable tubular member 120 and the tubular support member 315, the injection of the fluidic material 275 may also pressurize the annular region 120aa.

[000224] The continued injection of the fluidic material 275 may then pressurize the interior 120a of the expandable tubular member 120, thereby plastically deforming and radially expanding the expandable tubular member 120 off of the plurality of expansion cone segments 325. Because the outer surfaces 325bb and 325bc of each of the plurality of expansion cone segments 325 are tapered, the plastic deformation and radial expansion of the expandable tubular member 120 proximate the plurality of expansion cone segments 325 is facilitated. Furthermore, in an exemplary embodiment, the continued injection of the fluidic material 275 also pressurizes the annular region 120aa defined between the interior surface of the expandable tubular member 120 and the exterior surface of the tubular support member 315 that is bounded on the upper end by the packer cup assembly 340 and on the lower end by the expansion cone segments 325. Furthermore, in an exemplary embodiment, the pressurization of the annular region 120aa also radially expands at least a portion of the surrounding portion of the expandable tubular member 120. In this manner, the plastic deformation and radial expansion of the expandable tubular member 120 is enhanced. Furthermore, during operation of the apparatus 300, the packer cup assemblies 340 and 350 prevent the pressurized fluidic material 275 from passing above and beyond the packer cup assemblies 340 and



350 and thereby define the length of the pressurized annular region 120aa. In an exemplary embodiment, the pressurization of the annular region 120aa decreases the operating pressures required for plastic deformation and radial expansion of the expandable tubular member 120 by as much as 50% and also reduces the angle of attack of the tapered external surfaces 325bb and 325bc on each of the plurality of expansion cone segments 325.

[000225] The radial expansion of the expandable tubular member 120 may then continue until the upper end 120b of the expandable tubular member 120 is radially expanded and plastically deformed along with the overlapping portion of the wellbore casing 110. Because the expansion cone segments 325 may be adjustably positioned from an outside diameter less than the inside diameter of the expandable tubular member 120 to an outside diameter substantially equal to the inside diameter of the pre-existing casing 110, the resulting wellbore casing, including the casing 110 and the radially expanded tubular member 120, created by the operation of the apparatus 300, may have a single substantially constant inside diameter thereby providing a mono-diameter wellbore casing.

[000226] During the radial expansion process, the plurality of expansion cone segments 325 may be raised out of the expanded portion of the tubular member 120 by applying an upward axial force to the tubular support member 315. In a preferred embodiment, during the radial expansion process, the plurality of expansion cone segments 325 are raised at approximately the same rate as the tubular member 120 is expanded in order to keep the tubular member 120 stationary relative to the new wellbore section 115.

[000227] In a preferred embodiment, when the upper end portion of the expandable tubular member 120 and the lower portion of the wellbore casing 110 that overlap with one another are plastically deformed and radially expanded by the plurality of expansion cone segments 325, the plurality of expansion cone segments 325 are displaced out of the wellbore 100 by both the operating pressure within the interior of the tubular member 120 and a upwardly directed axial force applied to the tubular support member 305.

[000228] In a preferred embodiment, the operating pressure and flow rate of the fluidic material 275 is controllably ramped down when the plurality of expansion cone segments 325 reach the upper end portion of the expandable tubular member 120. In this manner, the sudden release of pressure caused by the complete radial expansion and plastic deformation of the expandable tubular member 120 off of the plurality of expansion cone segments 325 can be minimized. In a preferred embodiment, the operating pressure is reduced in a substantially linear fashion from 100% to about 10% during the end of the extrusion process beginning when the plurality of expansion cone segments 325 are within about 5 feet from completion of the extrusion process.

[000229] Alternatively, or in combination, the wall thickness of the upper end portion of the expandable tubular member 120 is tapered in order to gradually reduce the required operating pressure for plastically deforming and radially expanding the upper end portion of the tubular member 120. In this manner, shock loading of the apparatus 300 is reduced.

[000230] Alternatively, or in combination, a shock absorber is provided in the tubular support member 305 in order to absorb the shock caused by the sudden release of pressure. The shock absorber may comprise, for example, any conventional commercially available shock absorber, bumper sub, or jars adapted for use in wellbore operations.

[000231] Alternatively, or in combination, an expansion cone catching structure is provided in the upper end portion of the expandable tubular member 120 in order to catch or decelerate the expansion cone segments 325.

[000232] Alternatively, or in combination, during the radial expansion process, an upward axial force is applied to the tubular support member 315 sufficient to plastically deform and radially expand the tubular member 120 off of the external surfaces, 225bb and 225bc, of the expansion cone segments 325.

[000233] Alternatively, or in combination, in order to facilitate the pressurization of the interior 120a of the expandable tubular member by the injection of the fluidic materials 275, the region within the wellbore section 115 below the apparatus 300 may be fluidically sealed off in a convention manner using, for example, a packer.

[000234] Once the radial expansion process is completed, the tubular support member 305, the tubular support member 310, the tubular support member 315, the end stop 320, the expansion cone segments 325, the split ring collar 330, the collet assembly 335, the packer cup assembly 340, the spacer 345, the packer cup assembly 350, and the collet assembly 355 are removed from the wellbores 100 and 115.

[000235] Referring to Figs. 6, 6a, 6b, 6c, 6d, 6e, 6f, 6g, 6h, 6i, 6j, and 6k, an alternative embodiment of an apparatus 400 for forming a wellbore casing in a subterranean formation will now be described. The apparatus 400 includes a tubular support member 405 defining an internal passage 405a that is coupled to an end of a tubular coupling 410 defining an internal passage 410a. The other end of the tubular coupling 410 is coupled to an end of a tubular support member 415 defining an internal passage 415a that includes a first flange 415b, a first radial passage 415c, a second radial passage 415d, a second flange 415e, a stepped flange 415f, a third flange 415g, a fourth flange 415h, a fifth flange 415i, and an expansion cone body 415j. The other end of the tubular support member 415 is coupled to a tubular end stop 420 that defines a passage 420a.

[000236] As illustrated in Figs. 6e and 6f, the expansion cone support body 415j includes a first end 415ja, a tapered hexagonal portion 415jb that includes a plurality of T-shaped slots 415jba provided on each of the external faceted surfaces of the tapered hexagonal portion 415jb, and a second end 415jc. In an exemplary embodiment, the angle of attack of the tapered hexagonal portion 415jb ranges from about 35 to 50 degrees for reasons to be described.

[000237] As illustrated in Figs. 6, 6a, 6b, 6c, 6d, 6g, 6h, and 6i, a plurality of expansion cone segments 425 are provided with each including a first end 425a that includes T-shaped retaining member 425aa, second end 425b that includes a T-shaped retaining member 425ba that is operable to mate with and be received within corresponding T-shaped slots 415jba on the tapered hexagonal portion 415jb of the expansion cone support body 415j, a first external surface 425bb, a second external surface 425bc, and a third external surface 425bd. In an exemplary embodiment, a total of six expansion cone segments 425 are provided that are slidably coupled to corresponding sides of the tapered hexagonal portion 415jb of the expansion cone support body 415j.

[000238] In an exemplary embodiment, the width of the first external surface 425bb of each expansion cone segment 425 increases in the direction of the second external surface 425bc, the width of the second external surface 425bc is substantially constant, and the width of the third external surface 425bd decreases in the direction of the first end 425a of each expansion cone segment 225 for reasons to be described. In an exemplary embodiment, the first external surface 425bb of each expansion cone segment 425 tapers upwardly in the direction of the second external surface 425bc, the second external surface 425bc tapers upwardly in the direction of the third external surface 425bd, and the third external surface 425bd tapers downwardly in the direction of the first end 425a of each expansion cone segment 425 for reasons to be described. In an exemplary embodiment, the angle of attack of the taper of the first external surface 425bb of each expansion cone segment 425 is greater than the angle of attack of the taper of the second external surface 425bc. In an exemplary embodiment, the first external surface 425bb and second external surface 425bc of each expansion cone segment 425 are arcuate such that when the

plurality of expansion cone segments 425 are displaced in the direction of the end stop 420, the first external surface 425bb and second external surface 425bc of the plurality of expansion cone segments 425 provide a substantially continuous outer circumferential surface for reasons to be described.

[000239] As illustrated in Fig. 6j, in an exemplary embodiment, the external surfaces 425bb, 425bc, and 425bd, of the second ends 425b of the plurality of expansion cone segments 425 are adapted to mate with each another in order to interlock adjacent expansion cone segments 425.

[000240] As illustrated in Figs. 6, 6a, 6b, 6c, 6d, and 6k, a split ring collar 430 that defines a passage 430a for receiving the tubular support member 415 and includes a first end with a plurality of T-shaped slots 430b for receiving and mating with corresponding T-shaped retaining members 425aa of the plurality of expansion cone segments 425 and a second end that includes an L-shaped retaining member 430c. In an exemplary embodiment, the split ring collar 430 is a conventional split ring collar commercially available from Halliburton Energy Services modified in accordance with the teachings of the present disclosure.

[000241] A dog assembly 435 is provided that includes a tubular sleeve 435a that defines a passage 435aa for receiving the tubular support member 415 and includes a first end having a slot 435ab for receiving and mating with the L-shaped retaining member 430c of the split ring collar 430, a radial passage 435ac, and a recess 435ad for receiving the fifth flange 415a of the tubular support member 415. A second end of the tubular sleeve 435a includes a flange 435ae that mates with the fourth flange 415h of the tubular support member 415. A retaining ring 435b that defines a passage 435ba for receiving the fifth flange 415i is received within the recess 435ad of the tubular sleeve 435a and is coupled to an end of a load transfer pin 435c. The opposite end of the load transfer pin 435c is received within the radial passage 435ac of the tubular sleeve 435a and is coupled to an end of a tubular sleeve 435d that includes a recess 435da at a first end for receiving the tubular sleeve 435a and a radial opening 435dc for receiving a conventional resilient dog 435e. A spring 435f and a ring 435g that defines a passage 435ga for receiving the tubular support member 415 are received within the recess 435ad of the tubular sleeve 435a between a first end of the recess 435ad and the fifth flange 415i of the tubular support member 415.

[000242] A first conventional packer cup assembly 440 that defines a passage 440a for receiving the tubular support member 415 includes a first end 440b that mates with the fourth flange 415g of the tubular support member 415, a conventional sealing cup 440c, and a second end 440d. A tubular spacer 445 that defines a passage 445a for receiving the tubular support member 415 includes a first end 445b that mates with the second end 440d of the first packer cup assembly 440 and a second end 445c. A second conventional packer cup assembly 450 that defines a passage 450a for receiving the tubular support member 415 includes a first end 450b that mates with the second end 445c of the spacer 445, a conventional sealing cup 450c, and a second end 450d that mates with the stepped flange 415f of the tubular support member 415.

[000243] A dog assembly 455 is provided that includes a tubular sleeve 455a that defines a passage 455aa for receiving the tubular support member 415. A first end of the tubular sleeve 455a includes a radial opening 455ab for receiving a conventional resilient dog 455b. A second end of the tubular sleeve 455a includes a recess 455ac and is coupled to an end of a load transfer pin 455c. The opposite end of the load transfer pin 455c is coupled to a retaining ring 455d that defines a passage 455da for receiving the tubular support member 415. A tubular sleeve 455e is received within the recess 455ac of the tubular sleeve 455a that defines a passage 455ea for receiving the tubular support member 415 and includes a first end that includes a radial passage 455eb for receiving the load transfer pin 455c and a recess 455ec for receiving a spring 455f. A ring 455g that defines a passage 455ga for receiving the tubular support member 415 is further received within the recess 455ec of the tubular sleeve 455e

between the spring 455f and the second flange 415e of the tubular support member 415. A second end of the tubular sleeve 455e includes a radial passage 455ed, sealing members 455ef and 455eg, and a recess 455eh that mates with the first flange 415b of the tubular support member 415.

[000244] In an exemplary embodiment, during operation of the apparatus 400, as illustrated in Figs. 6, 6a, 6b, 6c, 6d, 6e, 6f, 6g, 6h, 6i, and 6k, the apparatus 400 may be initially positioned in the wellbore 100, within the casing 110, with the dog assemblies 435 and 455 positioned in a neutral position in which the radial passage 415d of the tubular support member 415 is fluidically coupled to the radial passage 455ed of the dog assembly 455 and the plurality of expansion cone segments 425 are not driven up the tapered hexagonal portion 415jb of the expansion cone support body 415j of the tubular support member 415 and into contact with the stop member 320. In this manner, fluidic materials within the interior 415a of the tubular support member 415 may pass through the radial passages, 415d and 455ed, into the annulus between the apparatus 400 and the casing 110, thereby preventing over pressurization of the annulus. Furthermore, in this manner, the outside diameter of the plurality of expansion cone segments 425 is less than or equal to the outside diameter of the stop member 420 thereby permitting the apparatus 400 to be displaced within the casing 110.

[000245] As illustrated in Figs. 7, 7a, 7b, and 7c, the apparatus 400 may then be positioned in the tubular member 120. During the insertion of the apparatus 400 into the tubular member 120, the upper end 120b of the tubular member 120 may impact the ends of the resilient dogs 435e and 455b of the dog assemblies 435 and 455, respectively, thereby driving the resilient dogs 435e and 455b backwards off of and adjacent to one side of the flanges 415h and 415f, respectively. As a result of the backward axial displacement of the resilient dog 435e, the tubular sleeve 435d, the pin 435c, the retaining ring 435b, and the ring 435g of the dog assembly 435 are driven backward thereby compressing the spring 435f and applying an axial biasing force to the tubular sleeve 435a that prevents the plurality of expansion cone segments 425 from being displaced toward the end stop 420. As a result of the backward axial displacement of the resilient dog 455b, the tubular sleeve 455a, the pin 455c, the retaining ring 455d, and the ring 455g of the dog assembly 455 are driven backward thereby compressing the spring 455f and applying an axial biasing force to the tubular sleeve 455e that prevents the radial passages 415d and 455ed from being fluidically decoupled.

[000246] The apparatus 400 may then be positioned at least partially in the open hole section 115a of the wellbore section 115 and beyond the lower end 120c of the tubular member 120. In an exemplary embodiment, the portion of the apparatus 400 that includes the stop member 420, the plurality of expansion cone segments 425, the split ring collar 430, the dog assembly 435, the packer cup assembly 440, the spacer 445, the packer cup assembly 450, and the dog assembly 455 is then positioned in the open hole section 115a of the wellbore section 115, and beyond the lower end 120 of the tubular member 120 for reasons to be described. Because the dogs 435e and 455b of the dog assemblies 435 and 455, respectively, are resilient, once the apparatus 400 has been positioned in the open hole section 115a of the wellbore section 115, beyond the lower end 120c of the tubular member 120, the resilient dogs 435e and 455b of dog assemblies 435 and 455, respectively, may spring outwardly in the radial direction.

[000247] The apparatus 400 may then be repositioned at least partially back within the tubular member 120. During the re-insertion of the apparatus 400 into the tubular member 120, the lower end 120c of the tubular member 120 may impact the ends of the resilient dogs 435e and 455b of the dog assemblies 435 and 455, respectively, thereby driving the resilient dogs 435e and 455b forward until the resilient dogs 435e and 455b are positioned



beyond and adjacent to the other side of the flanges 415h and 415f, respectively, of the tubular support member 415.

[000248] As a result of the forward axial displacement of the resilient dog 435e, the tubular sleeve 435a, the retaining ring 435b, the pin 435c, the tubular sleeve 435d, the spring 435f, and the ring 435g of the dog assembly 435 are displaced in the forward axial direction thereby also displacing the split ring collar 430 and the plurality of expansion cone segments 425 in the forward axial direction. As a result, the plurality of expansion cone segments 425 are driven up the tapered hexagonal portion 415jb of the expansion cone support body 415j of the tubular support member 415 and into contact with the stop member 320.

[000249] As a result of the forward axial displacement of the resilient dog 455b, the tubular sleeve 455a, the pin 455c, the retaining ring 455d, the tubular sleeve 455e, the spring 455f, and the ring 455g of the dog assembly 455 are driven forward in the axial direction thereby fluidically decoupling the radial passages 415d and 455ed and fluidically coupling the radial passages 415c and 415d. As a result, fluidic materials within the tubular support member 415 may not pass into the annulus between the tubular support member 415 and the tubular member 120.

[000250] As a result of the forward axial displacement of the resilient dog 435e, the outside diameter of the plurality of expansion cone segments 425 is made greater than the inside diameter of expandable tubular member 120, thereby permitting the apparatus 400 to be used to radially expand and plastically deform the tubular member 120, and fluidic materials within the interior 415a of the tubular support member 415 may no longer pass through the radial passages 415d and 455ed and into the annulus between the apparatus 400 and the tubular member 120, thereby permitting the interior of the apparatus 400 to be pressurized.

[000251] The apparatus 400 may then be operated to radially expand and plastically deform the tubular member 120 by applying an upward axial force to the tubular support member 415 and/or by injecting a pressurized fluidic material into the tubular support member 120.

[000252] In particular, as illustrated in Figs. 8, 8a, 8b, 8c, and 8d, the expandable tubular member 120 may then be radially expanded using the apparatus 400 by injecting a fluidic material 275 into the apparatus 400 through the passages 405a, 310a, 415a, and 420a. The injection of the fluidic material 275 may pressurize the interior 120a of the expandable tubular member 120. In addition, because the packer cup assemblies 440 and 450 seal off an annular region 120aa below the packer cup assemblies 440 and 450 and between the expandable tubular member 120 and the tubular support member 415, the injection of the fluidic material 275 may also pressurize the annular region 120aa.

[000253] The continued injection of the fluidic material 275 may then pressurize the interior 120a of the expandable tubular member 120 thereby plastically deforming and radially expanding the expandable tubular member 120 off of the plurality of expansion cone segments 425. Because the outer surfaces 425bb and 425bc of the plurality of expansion cone segments 425 are tapered, the plastic deformation and radial expansion of the expandable tubular member 120 proximate the plurality of expansion cone segments 425 is facilitated.

Furthermore, in an exemplary embodiment, the continued injection of the fluidic material 275 also pressurizes the annular region 120aa defined between the interior surface of the expandable tubular member 120 and the exterior surface of the tubular support member 415 which is bounded on the upper end by the packer cup assembly 440 and on the lower end by the plurality of expansion cone segments 425. Furthermore, in an exemplary embodiment, the pressurization of the annular region 120aa also radially expands at least a portion of the surrounding portion of the expandable tubular member 120. In this manner, the plastic deformation and radial expansion of the expandable tubular member 120 is enhanced. Furthermore, during operation of the apparatus 400, the packer cup assemblies

440 and 450 prevent the pressurized fluidic material 275 from passing above and beyond the packer cup assemblies 440 and 450 and thereby define the length of the pressurized annular region 120aa. In an exemplary embodiment, the pressurization of the annular region 120aa decreases the operating pressures required for plastic deformation and radial expansion of the expandable tubular member 120 by as much as 50% and also reduces the angle of attack of the tapered external surfaces 425bb and 425bc of the plurality of expansion cone segments 425.

[000254] The radial expansion of the expandable tubular member 120 may then continue until the upper end 120b of the expandable tubular member 120 is radially expanded and plastically deformed along with the overlapping portion of the wellbore casing 110. Because the plurality of expansion cone segments 425 may be adjustably positioned from an outside diameter which is less than the inside diameter of the expandable tubular member 120 to an outside diameter which is substantially equal to the inside diameter of the pre-existing casing 110, the resulting wellbore casing, including the casing 110 and the radially expanded tubular member 120 which is created by the operation of the apparatus 400, may have a single substantially constant inside diameter thereby providing a mono-diameter wellbore casing.

[000255] During the radial expansion process, the plurality of expansion cone segments 425 may be raised out of the expanded portion of the tubular member 120 by applying an upward axial force to the tubular support member 415. In a preferred embodiment, during the radial expansion process, the expansion cone segments 425 are raised at approximately the same rate as the tubular member 120 is expanded in order to keep the tubular member 120 stationary relative to the new wellbore section 115.

[000256] In a preferred embodiment, when the upper end portion of the expandable tubular member 120 and the lower portion of the wellbore casing 110 that overlap with one another are plastically deformed and radially expanded by the plurality of expansion cone segments 425, the plurality of expansion cone segments 425 are displaced out of the wellbore 100 by both the operating pressure within the interior of the tubular member 120 and an upwardly directed axial force applied to the tubular support member 405.

[000257] In a preferred embodiment, the operating pressure and flow rate of the fluidic material 275 is controllably ramped down when the plurality of expansion cone segments 425 reach the upper end portion of the expandable tubular member 120. In this manner, the sudden release of pressure caused by the complete radial expansion and plastic deformation of the expandable tubular member 120 off of the plurality of expansion cone segments 425 can be minimized. In a preferred embodiment, the operating pressure is reduced in a substantially linear fashion from 100% to about 10% during the end of the extrusion process beginning when the plurality of expansion cone segments 425 are within about 5 feet from completion of the extrusion process.

[000258] Alternatively, or in combination, the wall thickness of the upper end portion of the expandable tubular member 120 is tapered in order to gradually reduce the required operating pressure for plastically deforming and radially expanding the upper end portion of the tubular member 120. In this manner, shock loading of the apparatus is reduced.

[000259] Alternatively, or in combination, a shock absorber is provided in the tubular support member 405 in order to absorb the shock caused by the sudden release of pressure. The shock absorber may comprise, for example, any conventional commercially available shock absorber, bumper sub, or jars adapted for use in wellbore operations.

[000260] Alternatively, or in combination, an expansion cone catching structure is provided in the upper end portion of the expandable tubular member 120 in order to catch or decelerate the expansion cone segments 425.

[000261] Alternatively, or in combination, during the radial expansion process, an upward axial force is applied to the tubular support member 415 sufficient to plastically deform and radially expand the tubular member 120 off of the external surfaces 225bb and 225bc of the plurality of expansion cone segments 425.

[000262] Alternatively, or in combination, in order to facilitate the pressurization of the interior 120a of the expandable tubular member 120 by the injection of the fluidic materials 275, the region within the wellbore section 115 below the apparatus 400 may be fluidically sealed off in a convention manner using, for example, a packer.

[000263] Once the radial expansion process is completed, the tubular support member 405, the tubular support member 410, the tubular support member 415, the end stop 420, the expansion cone segments 425, the split ring collar 430, the dog assembly 435, the packer cup assembly 440, the spacer 445, the packer cup assembly 450, and the dog assembly 455 are removed from the wellbores 100 and 115.

[000264] Referring now to Figs. 9, 9a, 10 and 10a, an embodiment of an expansion cone assembly 500 will be described. The assembly 500 includes a tubular support member 505 that defines a passage 505a and includes a flange 505b, an expansion cone support flange assembly 505c, and an end stop 505d. The expansion cone support flange assembly 505c includes a tubular body 505ca and a plurality of equally spaced apart expansion cone segment support members 505cb that extend outwardly from the tubular body in the radial direction such that each includes identical bases 505cba and extensions 505cbb. The support members 505cb further include first sections 505cbc having arcuate conical outer surfaces and second sections 505cbd having arcuate cylindrical outer surfaces for reasons to be described.

[000265] An expansion cone segment assembly 510 is provided that includes a tubular support 510a defining a passage 510aa for receiving the tubular support member 505 and a slot 510ab. A plurality of spaced apart and substantially identical resilient expansion cone segment collets 510b extend from the tubular support 510a in the axial direction that include expansion cone segments 510ba extending therefrom in the axial direction. Each of the expansion cone segments 510ba further include arcuate conical expansion surfaces 510baa for radially expanding an expandable tubular member.

[000266] A split ring collar 515 is provided that defines a passage 515a for receiving the tubular support member 505 that includes an L-shaped retaining member 515b at one end for mating with the slot 510ab of the tubular support 510a of the expansion cone segment assembly 510. Another end of the split ring collar 515 includes an L-shaped retaining member 515c. A tubular sleeve 520 is provided that defines a passage 520a for receiving the tubular support member 505 and which includes a slot 520b for receiving the L-shaped retaining member 515c of the split ring collar 515.

[000267] During operation, the assembly 500 begins in an unexpanded position, as illustrated in Figs. 9 and 9a, with the plurality of expansion cone segments 510ba of the expansion cone segment assembly 510 positioned adjacent to the base of the conical section 505cbc of the expansion cone segment support members 505cb, and with the outside diameter of the plurality of expansion cone segments 510ba less than or equal to the maximum outside diameter of the assembly 500. The assembly 500 may then be expanded, as illustrated in Figs. 10 and 10a, by displacing the tubular sleeve 520, the split ring collar 515, and the expansion cone segment assembly 510 in the axial direction towards the expansion cone segment support members 505cb. As a result, the plurality of expansion cone segments 510ba are driven up the conical section 505cbc of the expansion cone segment support members 505cb and then onto the cylindrical section 505cbd of the expansion cone segment support members 505cb until the plurality of expansion cone segments 510ba engage the end stop 505d. In this manner, the outside diameter of the plurality of expansion segments 510ba is made greater than the maximum diameter of the remaining components of

the assembly 500. Furthermore, the conical outer surfaces 510baa of the plurality of expansion cone segments 510ba may now be used to radially expand a tubular member. In an exemplary embodiment, the extensions 505cbb of the expansion cone segment support members 505cb provide support in the circumferential direction to adjacent expansion cone segments 510ba. In an exemplary embodiment, the outer conical surfaces 510baa of the plurality of expansion cone segments 510ba in the expanded position of the assembly 500 provide a substantially continuous outer conical surfaces in the circumferential direction.

[000268] The assembly 500 may then be returned to the unexpanded position by displacing the tubular sleeve 520, the split ring collar 515, and the expansion cone segment assembly 510 in the axial direction away from the expansion cone segment support members 505cb. As a result, the plurality of expansion cone segments 510ba are displaced off of the cylindrical section 505cbd and the conical section 505cbc of the expansion cone segment support members 505cb. Because the collets 510b of the expansion cone segment assembly 510 are resilient, the expansion segments 510ba are thereby returned to a position in which the outside diameter of the plurality of expansion cone segments 510ba is less than or equal to the maximum diameter of the remaining components of the assembly 500.

[000269] In several alternative embodiments, the assembly 500 is incorporated into the assemblies 200, 300 and/or 400, described above with reference to Figs. 1, 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h, 1i, 1j, 1k, 1l, 1m, 2, 2a, 2b, 2c, 2d, 2e, 2f, 2g, 2h, 3, 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j, 4, 4a, 4b, 4c, 4d, 5, 5a, 5b, 5c, 5d, 6, 6a, 6b, 6c, 6d, 6e, 6f, 6g, 6h, 6i, 6j, 6k, 7, 7a, 7b, 7c, 8, 8a, 8b, 8c, and 8d.

[000270] Referring now to Figs. 11, 11a, 12 and 12a, an embodiment of an expansion cone assembly 600 will be described. The assembly 600 includes a tubular support member 605 that defines a passage 605a and includes an expansion cone support flange assembly 605b and an end stop 605c. The expansion cone support flange assembly 605b includes a tubular body 605ba and a plurality of substantially identical equally spaced apart expansion cone segment support members 605bb that extend outwardly from the tubular body 605ba in the radial direction. The support members 605bb further include first sections 605bba having arcuate cylindrical outer surfaces, second sections 605bbb having arcuate conical outer surfaces, and third sections 605bbc having arcuate cylindrical outer surfaces for reasons to be described.

[000271] An expansion cone segment assembly 610 is provided that includes a tubular support 610a defining a passage 610aa for receiving the tubular support member 605 and a slot 610ab. A plurality of spaced apart and substantially identical resilient expansion cone segment collets 610b extend from the tubular support 610a in the axial direction and include expansion cone segments 610ba extending therefrom in the axial direction. Each of the expansion cone segments 610ba further include arcuate conical expansion surfaces 610baa for radially expanding an expandable tubular member.

[000272] A split ring collar 615 is provided that defines a passage 615a for receiving the tubular support member 605 and which includes an L-shaped retaining member 615b at one end for mating with the slot 610ab of the tubular support 610a of the expansion cone segment assembly 610. Another end of the split ring collar 615 includes an L-shaped retaining member 615c. A tubular sleeve 620 is provided that defines a passage 620a for receiving the tubular support member 605 and which includes a slot 620b for receiving the L-shaped retaining member 615c of the split ring collar 615.

[000273] During operation, the assembly 600 begins in an unexpanded position, as illustrated in Figs. 11 and 11a, with the plurality of expansion cone segments 610ba of the expansion cone segment assembly 610 positioned adjacent to the base of the conical section 605bbb and on the cylindrical section 605bba of the expansion cone



segment support members 605bb, which results in the outside diameter of the plurality of expansion cone segments 610ba being less than or equal to the maximum outside diameter of the assembly 600. The assembly 600 may then be expanded, as illustrated in Figs. 12 and 12a, by displacing the tubular sleeve 620, the split ring collar 615, and the expansion cone segment assembly 610 in the axial direction towards the expansion cone segment support members 605bb. As a result, the plurality of expansion cone segments 610ba are driven up the conical section 605bbb of the expansion cone segment support members 605bb and onto the cylindrical section 605bbc of the expansion cone segment support members 605bb until the plurality of expansion cone segments 610ba engage the end stop 605c. In this manner, the outside diameter of the expansion segments 610ba is made greater than the maximum diameter of the remaining components of the assembly 600. Furthermore, the conical outer surfaces 610baa of the plurality of expansion cone segments 610ba may now be used to radially expand a tubular member. In an exemplary embodiment, the outer conical surfaces 610baa of the plurality of expansion cone segments 610ba in the expanded position of the assembly 600 provide a substantially continuous outer conical surfaces in the circumferential direction.

[000274] The assembly 600 may then be returned to the unexpanded position by displacing the tubular sleeve 620, the split ring collar 615, and the expansion cone segment assembly 610 in the axial direction away from the expansion cone segment support members 605bb. As a result, the plurality of expansion cone segments 610ba are displaced off of the cylindrical section 605bbc and the conical section 605bbb and back onto the cylindrical section 605bba of the expansion cone segment support members 605bb. Because the collets 610b of the expansion cone segment assembly 610 are resilient, the expansion segments 610ba are thereby returned to a position in which the outside diameter of the plurality of expansion cone segments 610ba is less than or equal to the maximum diameter of the remaining components of the assembly 600.

[000275] In several alternative embodiments, the assembly 600 is incorporated into the assemblies 200, 300 and/or 400, described above with reference to Figs. 1, 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h, 1i, 1j, 1k, 1l, 1m, 2, 2a, 2b, 2c, 2d, 2e, 2f, 2g, 2h, 3, 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j, 4, 4a, 4b, 4c, 4d, 5, 5a, 5b, 5c, 5d, 6, 6a, 6b, 6c, 6d, 6e, 6f, 6g, 6h, 6i, 6j, 6k, 7, 7a, 7b, 7c, 8, 8a, 8b, 8c, and 8d.

[000276] Referring now to Figs. 13, 13a, 13b, 13c, 14 and 14a, an embodiment of an expansion cone assembly 700 will be described. The assembly 700 includes a tubular support member 705 that defines a passage 705a and includes an expansion cone support flange assembly 705b and an end stop 705c. The expansion cone support flange assembly 705b includes a tubular body 705ba and a plurality of substantially identical equally spaced apart expansion cone segment support members 705bb that extend outwardly from the tubular body 705ba in the radial direction. The support members 705bb further include first sections 705bba having arcuate cylindrical outer surfaces, second sections 705bbb having arcuate conical outer surfaces, and third sections 705bbc having arcuate cylindrical outer surfaces for reasons to be described.

[000277] An expansion cone segment assembly 710 is provided that includes a first tubular support 710a defining a passage 710aa for receiving the tubular support member 705 and which includes a slot 710ab, and a second tubular support 710b defining a passage 710ba for receiving the tubular support member 705 and which includes a plurality of spaced apart and substantially identical axial slots 710bb. A plurality of spaced apart and substantially identical resilient expansion cone segment collets 710ac extend from the first tubular support 710a in the axial direction, are received within corresponding axial slots 710bb in the second tubular support 710b, and include substantially identical expansion cone segments 710aca which extend therefrom in the axial direction. A plurality of spaced apart and substantially identical resilient expansion cone segment collets 710bc extend from the

second tubular support 710b in the axial direction, are interleaved and overlap with the expansion cone segment collets 710ac, and include substantially identical expansion cone segments 710bca extending therefrom in the axial direction. Each of the expansion cone segments 710aca and 710bca further include arcuate conical expansion surfaces 710acaa and 710bcaa, respectively, for radially expanding an expandable tubular member. A plurality of pins 715a, 715b, 715c, and 715d couple the expansion cone segment collets 710ac to the second tubular support 710b.

[000278] A split ring collar 720 is provided that defines a passage 720a for receiving the tubular support member 705 and which includes an L-shaped retaining member 720b at one end for mating with the slot 710ab of the first tubular support 710a of the expansion cone segment assembly 710. Another end of the split ring collar 720 includes an L-shaped retaining member 720c. A tubular sleeve 725 is provided that defines a passage 725a for receiving the tubular support member 705 and which includes a slot 725b for receiving the L-shaped retaining member 720c of the split ring collar 720.

[000279] During operation, the assembly 700 begins in an unexpanded position, as illustrated in Figs. 13, 13a, 13b, and 13c, with the expansion cone segments 710aca of the expansion cone segment assembly 710 overlapping with and positioned over the expansion cone segments 710bca of the expansion cone segment assembly 710, positioned adjacent to the base of the conical section 705bbb of the expansion cone segment support members 705bb, with the outside diameter of the expansion cone segments 710aca and 710bca less than or equal to the maximum outside diameter of the assembly 700. As illustrated in Figs. 14 and 14a, the assembly 700 may then be expanded by displacing the tubular sleeve 725, the split ring collar 720, and the expansion cone segment assembly 710 in the axial direction towards the expansion cone segment support members 705bb. As a result, the expansion cone segments 710aca and 710bca are driven up the conical section 705bbb of the expansion cone segment support members 705bb and then onto the cylindrical section 705bbc of the expansion cone segment support members 705bb until the expansion cone segments 710aca and 710bca engage the end stop 705c. In this manner, the outside diameter of the expansion segments 710aca and 710bca is made greater than the maximum diameter of the remaining components of the assembly 700. Furthermore, the conical outer surfaces 710acaa and 710bcaa of the expansion cone segments 710aca and 710bca, respectively, may now be used to radially expand a tubular member. In an exemplary embodiment, the outer conical surfaces 710acaa and 710bcaa of the expansion cone segments 710aca and 710bca, respectively, in the expanded position of the assembly 700 provide a substantially continuous outer conical surfaces in the circumferential direction.

[000280] The assembly 700 may then be returned to the unexpanded position by displacing the tubular sleeve 720, the split ring collar 715, and the expansion cone segment assembly 710 in the axial direction away from the expansion cone segment support members 705bb. As a result, the expansion cone segments 710aca and 710bca are displaced off of the cylindrical section 705bbc and the conical section 705bbb and back onto the cylindrical section 705bba of the expansion cone segment support members 705bb. Because the collets 710ac and 710bc of the expansion cone segment assembly 710 are resilient, the expansion segments 710aca and 710bca are thereby returned to a position in which the outside diameter of the expansion cone segments 710aca and 710bca is less than or equal to the maximum diameter of the remaining components of the assembly 700.

[000281] In several alternative embodiments, the assembly 700 is incorporated into the assemblies 200, 300 and/or 400, described above with reference to Figs. 1, 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h, 1i, 1j, 1k, 1l, 1m, 2, 2a, 2b, 2c, 2d, 2e, 2f, 2g, 2h, 3, 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j, 4, 4a, 4b, 4c, 4d, 5, 5a, 5b, 5c, 5d, 6, 6a, 6b, 6c, 6d, 6e, 6f, 6g, 6h, 6i, 6j, 6k, 7, 7a, 7b, 7c, 8, 8a, 8b, 8c, and 8d.

[000282] Referring to Figs. 15, 15a, 15b, 15c, 15d, 15e, 15f, 15g, 15h, 15i, and 15j, an alternative embodiment of an apparatus 800 for forming a wellbore casing in a subterranean formation will now be described. The apparatus 800 includes a tubular support member 805 defining an internal passage 805a which is coupled to an end of a tubular coupling 810 defining an internal passage 810a. The other end of the tubular coupling 810 is coupled to an end of a tubular support member 815 defining an internal passage 815a having a throat passage 815aa that includes a first radial passage 815b, a first flange 815c having a second radial passage 815d, a second flange 815e having opposite shoulders 815ea and 815eb, a third flange 815f, and an expansion cone support body 815g. The other end of the tubular support member 815 is coupled to a tubular end stop 820 that defines a passage 820a.

[000283] As illustrated in Figs. 15d and 15e, the expansion cone support body 815g includes a first end 815ga, a tapered hexagonal portion 815gb that includes a plurality of T-shaped slots 815gba provided on each of the external faceted surfaces of the tapered hexagonal portion 815gb, and a second end 815gc. In an exemplary embodiment, the angle of attack of the tapered hexagonal portion 815gb ranges from about 35 to 50 degrees for reasons to be described.

[000284] As illustrated in Figs. 15, 15a, 15b, 15c, 15f, 15g, 15h, 15i, and 15j, a plurality of expansion cone segments 825 are provided with each including a first end 825a that includes a T-shaped retaining member 825aa, a second end 825b that includes a T-shaped retaining member 825ba that is operable to mate with and be received within corresponding T-shaped slots 815gba on the tapered hexagonal portion 815gb of the expansion cone support body 815g, a first external surface 825bb, a second external surface 825bc, and a third external surface 825bd. In an exemplary embodiment, a total of six expansion cone segments 825 are provided that are slidably coupled to corresponding sides of the tapered hexagonal portion 815gb of the expansion cone support body 815g.

[000285] In an exemplary embodiment, the width of the first external surface 825bb of each expansion cone segment 825 increases in the direction of the second external surface 825bc, the width of the second external surface 825bc is substantially constant, and the width of the third external surface 825bd decreases in the direction of the first end 825a of each expansion cone segment 825 for reasons to be described. In an exemplary embodiment, the first external surface 825bb of each expansion cone segment 825 tapers upwardly in the direction of the second external surface 825bc, the second external surface 825bc tapers upwardly in the direction of the third external surface 825bd, and the third external surface 825bd tapers downwardly in the direction of the first end 825a of each expansion cone segment 825 for reasons to be described. In an exemplary embodiment, the angle of attack of the taper of the first external surface 825bb of each expansion cone segment 825 is greater than the angle of attack of the taper of the second external surface 825bc. In an exemplary embodiment, the first external surface 825bb and second external surfaces 825bc of each expansion cone segment 825 are arcuate such that when the plurality of expansion cone segments 825 are displaced in the direction of the end stop 420, the first external surface 825bb and second external surfaces 825bc of the plurality expansion cone segments 825 provide a substantially continuous outer circumferential surface for reasons to be described.

[000286] As illustrated in Fig. 15i, in an exemplary embodiment, the external surfaces 825bb, 825bc, and 825bd, of the second ends 825b of the plurality expansion cone segments 825 are adapted to mate with each other in order to interlock adjacent expansion cone segment 825.

[000287] As illustrated in Figs. 15, 15c, and 15j, a split ring collar 830 that defines a passage 830a for receiving the tubular support member 815 and includes a first end with a plurality of T-shaped slots 830b for receiving and mating with corresponding T-shaped retaining members 825aa of the plurality of expansion cone segments 825 and a second end that includes an L-shaped retaining member 830c. In an exemplary embodiment, the split ring collar

830 is a conventional split ring collar commercially available from Halliburton Energy Services modified in accordance with the teachings of the present disclosure.

[000288] A dog assembly 835 is provided that includes a tubular sleeve 835a which defines a passage 835aa for receiving the tubular support member 815, and includes a slot 835ab for receiving and mating with the L-shaped retaining member 830c of the split ring collar 830, a counterbore 835ac, and a radial passage 835ad. An end of a load transfer pin 835b passes through the radial passage 835ad and is coupled to a retaining ring 835c which defines a passage 835ca for receiving the flange 815f of the tubular support member 815 and which is received within the counterbore 835ac of the tubular sleeve 835a. A ring 835d that defines a passage 835da for receiving the tubular support member 815 and a spring 835e are also received within the counterbore 835ac of the tubular sleeve 835a between the flange 815f and the end of the counterbore 835ac. The other end of the load transfer pin 835b is coupled to an end of a tubular sleeve 835f which includes a counterbore 835fa for receiving the tubular sleeve 835a, a radial passage 835fb for receiving a conventional resilient dog 835g, a counterbore 835fc for receiving and mating with the flange 815e of the tubular support member 815, a flange 835fd, a flange 835fe including counterbores 835ff and 835fg that mate with and receive the flange 815c of the tubular support member 815, and a radial passage 835fh.

[000289] A first conventional packer cup assembly 840 that defines a passage 440a for receiving the tubular sleeve 835f includes a first end 840b that mates with the flange 835fd of the tubular sleeve 835f, a conventional sealing cup 840c, and a second end 840d. A tubular spacer 845 that defines a passage 845a for receiving the tubular sleeve 835f includes a first end 845b that mates with the second end 840d of the first packer cup assembly 840 and a second end 845c. A second conventional packer cup assembly 850 that defines a passage 850a for receiving the tubular sleeve 835f includes a first end 850b that mates with the second end 845c of the spacer 845, a conventional sealing cup 850c, and a second end 850d that mates with the flange 835fe of the tubular sleeve 835f.

[000290] In an exemplary embodiment, during operation of the apparatus 800, as illustrated in Figs. 15, 15a, 15b, 15c, 15d, 15e, 15f, 15g, 15h, 15i, and 15j, the apparatus 800 may be initially positioned in the wellbore 100, within the casing 110, with the dog assembly 835 positioned in a neutral position in which the radial passage 815d of the tubular support member 815 is fluidically coupled to the radial passage 835fh of the dog assembly 835 and the plurality of expansion cone segments 825 are not driven up the tapered hexagonal portion 815gb of the expansion cone support body 815g of the tubular support member 815 into contact with the stop member 320. In this manner, fluidic materials within the interior 815a of the tubular support member 815 may pass through the radial passages 815d and 835fh and into the annulus between the apparatus 800 and the casing 110, thereby preventing over pressurization of the annulus. Furthermore, in this manner, the outside diameter of the plurality of expansion cone segments 825 is less than or equal to the outside diameter of the stop member 820, thereby permitting the apparatus 800 to be displaced within the casing 110.

[000291] As illustrated in Figs. 16, 16a, 16b, and 16c, the apparatus 800 may then be positioned in the tubular member 120. During the insertion of the apparatus 800 into the tubular member 120, the upper end 120b of the tubular member 120 may engage the end of the resilient dog 835g of the dog assembly 835 thereby driving the resilient dog 835g backwards onto the shoulder 815ea of the flange 815e of the tubular support member 815. As a result of the backward axial displacement of the resilient dog 835g, the tubular sleeve 835f, the pin 835b, the retaining ring 835c, the ring 835d, and the spring 835e of the dog assembly 835 are driven backward thereby compressing the spring 835e and applying an axial biasing force to the tubular sleeve 835a that prevents the plurality of expansion cone segments 825 from being displaced toward the end stop 820.



[000292] The apparatus 800 may then be at least partially positioned in the open hole section 115a of the wellbore section 115, beyond the lower end 120c of the tubular member 120. In an exemplary embodiment, that portion of the apparatus 800 that includes the stop member 820, the plurality of expansion cone segments 825, the split ring collar 830, and the dog assembly 835 is then positioned in the open hole section 115a of the wellbore section 115, beyond the lower end 120c of the tubular member 120 for reasons to be described. Because the dog 835g of the dog assembly 835 is resilient, once the apparatus 800 has been positioned in the open hole section 115a of the wellbore section 115, beyond the lower end 120c of the tubular member 120, the resilient dog 835g of the dog assembly 835 may spring outwardly in the radial direction.

[000293] The apparatus 800 may then be repositioned at least partially back within the tubular member 120. During the re-insertion of the apparatus 800 into the tubular member 120, the lower end 120c of the tubular member 120 may impact the ends of the resilient dog 835g of the dog assembly 835, thereby driving the resilient dog 835g forward until the resilient dog 835g is positioned onto the shoulder 815eb of the flange 815e of the tubular support member 815.

[000294] As a result of the forward axial displacement of the resilient dog 835g, the tubular sleeve 835f, the spring 835e, the ring 835d, the ring 835c, the pin 835b, and the tubular sleeve 835a are displaced in the forward axial direction, thereby displacing the split ring collar 830 and the plurality of expansion cone segments 825 in the forward axial direction. As a result, the plurality of expansion cone segments 825 are driven up the tapered hexagonal portion 815gb of the expansion cone support body 815g of the tubular support member 815 and into contact with the stop member 320. Furthermore, as a result of the forward axial displacement of the tubular sleeve 835f, the radial passages 815d and 835fh are fluidically decoupled. As a result, fluidic materials within the tubular support member 815 may not pass into the annulus between the tubular support member and the tubular member 120.

[000295] As a result of the forward axial displacement of the resilient dog 435e, the outside diameter of the plurality of expansion cone segments 825 is made greater than the inside diameter of expandable tubular member 120, thereby permitting the apparatus 800 to be used to radially expand and plastically deform the tubular member 120, and fluidic materials within the interior 815a of the tubular support member 815 may no longer pass through the radial passages 815d and 935fh and into the annulus between the apparatus 800 and the tubular member 120, thereby permitting the interior of the apparatus 800 to be pressurized.

[000296] The apparatus 800 may then be operated to radially expand and plastically deform the tubular member 120 by applying an upward axial force to the tubular support member 815 and/or by injecting a pressurized fluidic material into the tubular support member 815.

[000297] In particular, as illustrated in Figs. 17, 17a, 17b, and 17c, the expandable tubular member 120 may then be radially expanded using the apparatus 800 by injecting a fluidic material 275 into the apparatus 800 through the passages 805a, 810a, 815a, and 820a. The injection of the fluidic material 275 may pressurize the interior 120a of the expandable tubular member 120. In addition, because the packer cup assemblies 840 and 850 seal off an annular region 120aa below the packer cup assemblies 840 and 850 located between the expandable tubular member 120 and the tubular support member 815, the injection of the fluidic material 275 may also pressurize the annular region 120aa.

[000298] The continued injection of the fluidic material 275 may then pressurize the interior 120a of the expandable tubular member 120 thereby plastically deforming and radially expanding the expandable tubular member 120 off of the plurality of expansion cone segments 825. Because the outer surfaces 825bb and 825bc of

the plurality of expansion cone segments 825 are tapered, the plastic deformation and radial expansion of the expandable tubular member 120 proximate the plurality of expansion cone segments 825 is facilitated.

Furthermore, in an exemplary embodiment, the continued injection of the fluidic material 275 also pressurizes the annular region 120aa defined between the interior surface of the expandable tubular member 120 and the exterior surface of the tubular support member 815 which is bounded on the upper end by the packer cup assembly 840 and on the lower end by the plurality of expansion cone segments 825. Furthermore, in an exemplary embodiment, the pressurization of the annular region 120aa also radially expands at least a portion of the surrounding portion of the expandable tubular member 120. In this manner, the plastic deformation and radial expansion of the expandable tubular member 120 is enhanced. Furthermore, during operation of the apparatus 300, the packer cup assemblies 840 and 850 prevent the pressurized fluidic material 275 from passing above and beyond the packer cup assemblies 840 and 850 and thereby define the length of the pressurized annular region 120aa. In an exemplary embodiment, the pressurization of the annular region 120aa decreases the operating pressures required for plastic deformation and radial expansion of the expandable tubular member 120 by as much as 50% and also reduces the angle of attack of the tapered external surfaces 825bb and 825bc of the plurality of expansion cone segments 825.

[000299] The radial expansion of the expandable tubular member 120 may then continue until the upper end 120b of the expandable tubular member 120 is radially expanded and plastically deformed along with the overlapping portion of the wellbore casing 110. Because the plurality of expansion cone segments 825 may be adjustably positioned from an outside diameter which is less than the inside diameter of the expandable tubular member 120 to an outside diameter which is substantially equal to the inside diameter of the pre-existing casing 110, the resulting wellbore casing, including the casing 110 and the radially expanded tubular member 120, which is created by the operation of the apparatus 800 may have a single substantially constant inside diameter, thereby providing a mono-diameter wellbore casing.

[000300] During the radial expansion process, the plurality of expansion cone segments 825 may be raised out of the expanded portion of the tubular member 120 by applying an upward axial force to the tubular support member 815. In a preferred embodiment, during the radial expansion process, the plurality of expansion cone segments 825 are raised at approximately the same rate as the tubular member 120 is expanded in order to keep the tubular member 120 stationary relative to the new wellbore section 115.

[000301] In a preferred embodiment, when the upper end portion of the expandable tubular member 120 and the lower portion of the wellbore casing 110 that overlap with one another are plastically deformed and radially expanded by the plurality of expansion cone segments 825. The plurality of expansion cone segments 825 may be displaced out of the wellbore 100 by both the operating pressure within the interior of the tubular member 120 and an upwardly directed axial force applied to the tubular support member 805.

[000302] In a preferred embodiment, the operating pressure and flow rate of the fluidic material 275 is controllably ramped down when the plurality of expansion cone segments 825 reach the upper end portion of the expandable tubular member 120. In this manner, the sudden release of pressure caused by the complete radial expansion and plastic deformation of the expandable tubular member 120 off of the expansion cone segments 825 can be minimized. In a preferred embodiment, the operating pressure is reduced in a substantially linear fashion from 100% to about 10% during the end of the extrusion process beginning when the plurality of expansion cone segments 825 are within about 5 feet from completion of the extrusion process.

[000303] Alternatively, or in combination, the wall thickness of the upper end portion of the expandable tubular member 120 is tapered in order to gradually reduce the required operating pressure for plastically deforming and

radially expanding the upper end portion of the tubular member 120. In this manner, shock loading of the apparatus 800 is reduced.

[000304] Alternatively, or in combination, a shock absorber is provided in the tubular support member 805 in order to absorb the shock caused by the sudden release of pressure. The shock absorber may comprise, for example, any conventional commercially available shock absorber, bumper sub, or jars adapted for use in wellbore operations.

[000305] Alternatively, or in combination, an expansion cone catching structure is provided in the upper end portion of the expandable tubular member 120 in order to catch or at least decelerate the expansion cone segments 825.

[000306] Alternatively, or in combination, during the radial expansion process, an upward axial force is applied to the tubular support member 815 sufficient to plastically deform and radially expand the tubular member 120 off of the external surfaces 225bb and 225bc of the plurality of expansion cone segments 825.

[000307] Alternatively, or in combination, in order to facilitate the pressurization of the interior 120a of the expandable tubular member 120 by the injection of the fluidic materials 275, the region within the wellbore section 115 below the apparatus 800 may be fluidically sealed off in a convention manner using, for example, a packer.

[000308] Once the radial expansion process is completed, the tubular support member 805, the tubular support member 810, the tubular support member 815, the end stop 820, the plurality of expansion cone segments 825, the split ring collar 830, the dog assembly 835, the packer cup assembly 840, the spacer 845, and the packer cup assembly 850 are removed from the wellbores 100 and 115.

[000309] If the expansion cone segments 825 become lodged within the expandable tubular member 120 during the radial expansion process, then a ball 280 may be placed in the throat 815aa of the passage 815a of the tubular support member 815. The continued injection of the fluidic material 275 following the placement of the ball 280 in the throat 815aa of the passage 815a of the tubular support member will then pressurize the radial passage 815b and an annular portion 835fga of the counterbore 835fg. As a result of the pressurization of the annular portion 835fga of the counterbore 835fg, the tubular sleeve 835f, the pin 835b, the retaining ring 835c, the ring 835d, the spring 835e, the tubular sleeve 835a of the dog assembly 835, and the split ring collar 830 are driven backward thereby displacing the plurality of expansion cone segments 825 backwards in the axial direction away from the end stop 820. In this manner, the outside diameter of the plurality of expansion cone segments 825 is thereby reduced and the apparatus 800 may then be removed from the expandable tubular member 120.

[000310] Referring now to Figs. 18a, 18b, 18c, and 18d, an embodiment of an expansion cone assembly 900 will be described. The assembly 900 includes a tubular support member 905 that defines a passage 905a and includes an expansion cone support flange assembly 905b which is coupled to an end stop 910 that defines a passage 910a. The expansion cone support flange assembly 905b includes a first tubular end 905ba, a second tubular end 905bb, and an intermediate hexagonal conical tubular body 905bc that includes a plurality of substantially identical and equally spaced apart expansion cone segment support slots 905bcaa, 905bcab, 905bcac, 905bcad, 905bcae, and 905bcaf on each of the facets of the hexagonal tubular body.

[000311] A plurality of first expansion cone segments 915a, 915b, and 915c are provided that include T-shaped retaining members 915aa, 915ba, and 915ca, respectively, which are operable to mate with and are movably received within the T-shaped slots 905bcaa, 905bcac, and 905bcae of the hexagonal conical tubular body 905bc of the expansion cone support assembly 905b. The plurality of first expansion cone segments 915aa, 915ba, and 915ca also each include a T-shaped retaining member 915ab, 915bb, and 915cb, respectively, an exterior top

surface 915ac, 915bc, and 915cc, respectively, an exterior top surface 915ad, 915bd, and 915cd, respectively, an exterior top surface 915ae, 915be, and 915ce, respectively, an exterior top surface 915af, 915bf, and 915cf, respectively, and an exterior top surface 915ag, 915bg, and 915cg, respectively. In an exemplary embodiment, the exterior top surfaces 915ac, 915bc, and 915cc and the exterior top surfaces 915ad, 915bd, and 915cd are arcuate conical surfaces in which the angle of attack of the exterior top surfaces 915ac, 915bc, and 915cc is greater than the angle of attack of the exterior top surfaces 915ad, 915bd, and 915cd.

[000312] A plurality of second expansion cone segments 920a, 920b, and 920c, which are interleaved with and complementary shaped to the first expansion cone segments 915a, 915b, and 915c, are also provided. Each of the plurality of second expansion cone segments 920a, 920b, and 920c include a T-shaped retaining members 920aa, 920ba, and 920ca, respectively, that is operable to mate with and is movably received within the T-shaped slots 905bcab, 905bcad, and 905bcac, respectively, of the hexagonal conical tubular body 905bc of the expansion cone support assembly 905b. Each of the plurality of second expansion cone segments 920a, 920b, and 920c also include a T-shaped retaining member 920ab, 920bb, and 920cb, respectively, an exterior top surface 920ac, 920bc, and 920cc, respectively, an exterior top surface 920ad, 920bd, and 920cd, respectively, an exterior top surface 920ae, 920be, and 920ce, respectively, an exterior top surface 920af, 920bf, and 920cf, respectively, and an exterior top surface 920ag, 920bg, and 920cg. In an exemplary embodiment, the exterior top surfaces 920ac, 920bc, and 920cc and the exterior top surfaces 920ad, 920bd, and 920cd are arcuate conical surfaces in which the angle of attack of the exterior top surfaces 920ac, 920bc, and 920cc is greater than the angle of attack of the exterior top surfaces 920ad, 920bd, and 920cd.

[000313] A split ring collar 925 is provided which defines a passage 925a for receiving the tubular support member 905 and which includes an L-shaped retaining member 925b at one end of the split ring collar 925 and T-shaped slots, 925c, 925d, 925e, 925f, 925g, and 925h, at another end of the split ring collar which are operable to mate with and receive the T-shaped retaining members, 915ab, 920ab, 915bb, 920bb, 915cb, and 920cb, of the expansion cone segments, 915a, 920a, 915b, 920b, 915c, and 920c, respectively. A tubular sleeve 930 is provided that defines a passage 930a for receiving the tubular support member 905 and which includes a slot 930b for receiving and mating with the L-shaped retaining member 925b of the split ring collar 925.

[000314] During operation, the assembly 900 begins in an unexpanded position, as illustrated in Figs. 18a, 18b, 18c, and 18d, with the expansion cone segments 915a, 915b, 915c, 915d, 920a, 920b, 920c, and 920d positioned adjacent to the base of the hexagonal conical tubular body 905bc of the expansion cone support flange 905b and away from the end stop 910. In this manner, the outside diameter of the expansion cone segments 915a, 915b, 915c, 915d, 920a, 920b, 920c, and 920d is less than or equal to the maximum outside diameter of the assembly 900. Furthermore, in the unexpanded position, the expansion cone segments, 915a, 915b, and 915c, are positioned further away from the end stop 910 than the expansion cone segments, 920a, 920b, and 920c.

[000315] As illustrated in Figs. 19 and 19a, the assembly 900 may then be expanded by displacing the tubular sleeve 930 and the split ring collar 925 in the axial direction towards the expansion cone segment support members 705bb. As a result, the expansion cone segments 915a, 915b, 915c, 920a, 920b, and 920c, are driven up the hexagonal conical tubular body 905bc of the expansion cone support flange 905b until the expansion cone segments 915a, 915b, 915c, 920a, 920b, and 920c engage the end stop 910. In this manner, the outside diameter of the expansion cone segments 915a, 915b, 915c, 920a, 920b, and 920c, is greater than the maximum diameter of the remaining components of the assembly 900. Furthermore, the conical outer surfaces 915ac, 915bc, 915cc, 920ac, 920bc, and 920cc, and the conical outer surfaces 915ad, 915bd, 915cd, 920ad, 920bd, and 920cd, of the expansion



cone segments 915a, 915b, 915c, 920a, 920b, and 920c, respectively, may now be used to radially expand a tubular member. In an exemplary embodiment, the outer conical surfaces 915ac, 915bc, 915cc, 920ac, 920bc, and 920cc, and the conical outer surfaces 915ad, 915bd, 915cd, 920ad, 920bd, and 920cd, of the expansion cone segments 915a, 915b, 915c, 920a, 920b, and 920c, respectively, in the expanded position of the assembly 900, provide a substantially continuous outer conical surfaces in the circumferential direction. Furthermore, note that in the expanded position of the assembly 900, the first set of expansion cone segments 915a, 915b, and 915c, are brought into alignment with the second set of expansion cone segments 920a, 920b, and 920c.

[000316] The assembly 900 may then be returned to the unexpanded position by displacing the tubular sleeve 930 and the split ring collar 925 in the axial direction away from the end stop 910. As a result, the expansion cone segments 915a, 915b, 915c, 920a, 920b, and 920c, are displaced away from the end stop 910, down the conical hexagonal tubular member 905bc and are returned to a position in which the outside diameter of the expansion cone segments 915a, 915b, 915c, 920a, 920b, and 920c is less than or equal to the maximum diameter of the remaining components of the assembly 900.

[000317] In several alternative embodiments, the assembly 900 is incorporated into the assemblies 200, 300, 400, and 800 described above with reference to Figs. 1, 1a, 1b, 1c, 1d, 1e, 1f, 1g, 1h, 1i, 1j, 1k, 1l, 1m, 2, 2a, 2b, 2c, 2d, 2e, 2f, 2g, 2h, 3, 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j, 4, 4a, 4b, 4c, 4d, 5, 5a, 5b, 5c, 5d, 6, 6a, 6b, 6c, 6d, 6e, 6f, 6g, 6h, 6i, 6j, 6k, 7, 7a, 7b, 7c, 8, 8a, 8b, 8c, 8d, 15, 15a, 15b, 15c, 15d, 15e, 15f, 15g, 15h, 15i, 15j, 16, 16a, 16b, 16c, 17, 17a, 17b, and 17c.

[000318] Referring to Fig. 20a, an embodiment of an expansion cone segment assembly 1000 includes interlocking expansion cone segments, 1000a, 1000b, 1000c, 1000d, 1000e, and 1000f.

[000319] Referring to Fig. 20b, an embodiment of an expansion cone segment assembly 1100 includes interlocking expansion cone segments, 1100a, 1100b, 1100c, 1100d, 1100e, and 1100f.

[000320] Referring to Fig. 20c, an embodiment of an expansion cone segment assembly 1200 includes interlocking expansion cone segments, 1200a, 1200b, 1200c, 1200d, 1200e, and 1200f.

[000321] Referring to Fig. 20d, an embodiment of an expansion cone segment assembly 1300 includes interlocking expansion cone segments, 1300a, 1300b, 1300c, 1300d, 1300e, and 1300f.

[000322] Referring to Fig. 20e, an embodiment of an expansion cone segment assembly 1400 includes interlocking expansion cone segments, 1400a, 1400b, 1400c, 1400d, 1400e, and 1400f.

[000323] Referring to Fig. 20f, an embodiment of an expansion cone segment assembly 1500 includes interlocking expansion cone segments, 1500a, 1500b, 1500c, 1500d, 1500e, and 1500f.

[000324] Referring to Fig. 20g, an embodiment of an expansion cone segment assembly 1600 includes interlocking expansion cone segments, 1600a, 1600b, 1600c, 1600d, 1600e, and 1600f.

[000325] Referring to Fig. 20h, an embodiment of an expansion cone segment assembly 1700 includes interlocking expansion cone segments, 1700a, 1700b, 1700c, 1700d, 1700e, and 1700f.

[000326] Referring to Fig. 20i, an embodiment of an expansion cone segment assembly 1800 includes interlocking expansion cone segments, 1800a, 1800b, 1800c, 1800d, 1800e, and 1800f.

[000327] Referring to Fig. 20j, an embodiment of an expansion cone segment assembly 1900 includes interlocking expansion cone segments, 1900a, 1900b, 1900c, 1900d, 1900e, and 1900f.

[000328] Referring to Fig. 20k, an embodiment of an expansion cone segment assembly 2000 includes interlocking expansion cone segments, 2000a, 2000b, 2000c, 2000d, 2000e, and 2000f.

[000329] Referring to Fig. 20l, an embodiment of an expansion cone segment assembly 2100 includes interlocking expansion cone segments, 2100a, 2100b, 2100c, 2100d, 2100e, and 2100f.

[000330] Referring to Fig. 20m, an embodiment of an expansion cone segment assembly 2200 includes interlocking expansion cone segments, 2200a, 2200b, 2200c, 2200d, 2200e, and 2200f.

[000331] The expansion cone segment assemblies 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, and 2200 provide enhanced operational properties such as, for example, efficient radial expansion of expandable tubular members and durability during operation.

[000332] In several alternative embodiments, the design and operational features of the apparatus 200, 300, 400, and 800, and the assembly 500, 600, 700, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, and 2200 may be combined, in whole or in part, and/or the design and operational elements of the apparatus 200, 300, 400, and 800, and the assembly 500, 600, 700, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, and 2200 may be interspersed among each other.

[000333] In several alternative embodiments, the apparatus 200, 300, 400, and 800, and the assembly 500, 600, 700, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, and 2200 may be used to form or repair wellbore casings, pipelines, or structural supports.

[000334] In several alternative embodiments, the apparatus 200, 300, 400, and 800, and the assembly 500, 600, 700, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, and 2200 include two or more expansion cone segments that may be movably support and guided on a tapered expansion cone support body that may, for example, be conical, or may be a multi-sided body.

[000335] In several alternative embodiments, the design and operation of the apparatus 200, 300, 400, and 800, and the assembly 500, 600, 700, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, and 2200 are provided substantially as disclosed in one or more of the following: (1) U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, which claims priority from provisional application 60/121,702, filed on 2/25/99, (3) U.S. Patent Number 6,823,937, which was filed as U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (4) U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (5) U.S. patent application serial no. 10/169,434, attorney docket no. 25791.10.04, filed on 7/1/02, which claims priority from provisional application 60/183,546, filed on 2/18/00, (6) U.S. patent no. 6,640,903 which was filed as U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (7) U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (8) U.S. patent number 6,575,240, which was filed as patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, which claims priority from provisional application 60/121,907, filed on 2/26/99, (9) U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (10) U.S. patent application serial no. 09/981,916, attorney docket no. 25791.18, filed on 10/18/01 as a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent

Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (11) U.S. patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (12) U.S. patent application serial no. 10/030,593, attorney docket no. 25791.25.08, filed on 1/8/02, which claims priority from provisional application 60/146,203, filed on 7/29/99, (13) U.S. provisional patent application serial no. 60/143,039, attorney docket no. 25791.26, filed on 7/9/99, (14) U.S. patent application serial no. 10/111,982, attorney docket no. 25791.27.08, filed on 4/30/02, which claims priority from provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (15) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (16) U.S. provisional patent application serial no. 60/438,828, attorney docket no. 25791.31, filed on 1/9/03, (17) U.S. patent number 6,564,875, which was filed as application serial no. 09/679,907, attorney docket no. 25791.34.02, on 10/5/00, which claims priority from provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (18) U.S. patent application serial no. 10/089,419, filed on 3/27/02, attorney docket no. 25791.36.03, which claims priority from provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (19) U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (20) U.S. patent application serial no. 10/303,992, filed on 11/22/02, attorney docket no. 25791.38.07, which claims priority from provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (21) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (22) U.S. provisional patent application serial no. 60/455,051, attorney docket no. 25791.40, filed on 3/14/03, (23) PCT application US02/2477, filed on 6/26/02, attorney docket no. 25791.44.02, which claims priority from U.S. provisional patent application serial no. 60/303,711, attorney docket no. 25791.44, filed on 7/6/01, (24) U.S. patent application serial no. 10/311,412, filed on 12/12/02, attorney docket no. 25791.45.07, which claims priority from provisional patent application serial no. 60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (25) U.S. patent application serial no. 10/, filed on 12/18/02, attorney docket no. 25791.46.07, which claims priority from provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (26) U.S. patent application serial no. 10/322,947, filed on 1/22/03, attorney docket no. 25791.47.03, which claims priority from provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (27) U.S. patent application serial no. 10/406,648, filed on 3/31/03, attorney docket no. 25791.48.06, which claims priority from provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (28) PCT application US02/04353, filed on 2/14/02, attorney docket no. 25791.50.02, which claims priority from U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (29) U.S. patent application serial no. 10/465,835, filed on 6/13/03, attorney docket no. 25791.51.06, which claims priority from provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (30) U.S. patent application serial no. 10/465,831, filed on 6/13/03, attorney docket no. 25791.52.06, which claims priority from U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (31) U.S. provisional patent application serial no. 60/452,303, filed on 3/5/03, attorney docket no. 25791.53, (32) U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from

provisional application 60/111,293, filed on 12/7/98, (33) U.S. patent number 6,561,227, which was filed as patent application serial number 09/852,026, filed on 5/9/01, attorney docket no. 25791.56, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (34) U.S. patent application serial number 09/852,027, filed on 5/9/01, attorney docket no. 25791.57, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (35) PCT Application US02/25608, attorney docket no. 25791.58.02, filed on 8/13/02, which claims priority from provisional application 60/318,021, filed on 9/7/01, attorney docket no. 25791.58, (36) PCT Application US02/24399, attorney docket no. 25791.59.02, filed on 8/1/02, which claims priority from U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (37) PCT Application US02/29856, attorney docket no. 25791.60.02, filed on 9/19/02, which claims priority from U.S. provisional patent application serial no. 60/326,886, attorney docket no. 25791.60, filed on 10/3/2001, (38) PCT Application US02/20256, attorney docket no. 25791.61.02, filed on 6/26/02, which claims priority from U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (39) U.S. patent application serial no. 09/962,469, filed on 9/25/01, attorney docket no. 25791.62, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (40) U.S. patent application serial no. 09/962,470, filed on 9/25/01, attorney docket no. 25791.63, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (41) U.S. patent application serial no. 09/962,471, filed on 9/25/01, attorney docket no. 25791.64, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (42) U.S. patent application serial no. 09/962,467, filed on 9/25/01, attorney docket no. 25791.65, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (43) U.S. patent application serial no. 09/962,468, filed on 9/25/01, attorney docket no. 25791.66, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (44) PCT application US 02/25727, filed on 8/14/02, attorney docket no. 25791.67.03, which claims priority from U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, and U.S. provisional patent application serial no. 60/318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (45) PCT application US 02/39425, filed on 12/10/02, attorney docket no. 25791.68.02, which claims priority from U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001, (46) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (47) U.S. utility patent application serial no. 10/516,467, attorney docket no. 25791.70, filed on 12/10/01, which is a continuation application of U.S. utility



patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (48) PCT application US 03/00609, filed on 1/9/03, attorney docket no. 25791.71.02, which claims priority from U.S. provisional patent application serial no. 60/357,372, attorney docket no. 25791.71, filed on 2/15/02, (49) U.S. patent application serial no. 10/074,703, attorney docket no. 25791.74, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (50) U.S. patent application serial no. 10/074,244, attorney docket no. 25791.75, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (51) U.S. patent application serial no. 10/076,660, attorney docket no. 25791.76, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (52) U.S. patent application serial no. 10/076,661, attorney docket no. 25791.77, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (53) U.S. patent application serial no. 10/076,659, attorney docket no. 25791.78, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (54) U.S. patent application serial no. 10/078,928, attorney docket no. 25791.79, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (55) U.S. patent application serial no. 10/078,922, attorney docket no. 25791.80, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (56) U.S. patent application serial no. 10/078,921, attorney docket no. 25791.81, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (57) U.S. patent application serial no. 10/261,928, attorney docket no. 25791.82, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (58) U.S. patent application serial no. 10/079,276, attorney docket no. 25791.83, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (59) U.S. patent application serial no. 10/262,009, attorney docket no. 25791.84, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (60) U.S. patent application serial no. 10/092,481, attorney docket no. 25791.85, filed on 3/7/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney

docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (61) U.S. patent application serial no. 10/261,926, attorney docket no. 25791.86, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (62) PCT application US 02/36157, filed on 11/12/02, attorney docket no. 25791.87.02, which claims priority from U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/01, (63) PCT application US 02/36267, filed on 11/12/02, attorney docket no. 25791.88.02, which claims priority from U.S. provisional patent application serial no. 60/339,013, attorney docket no. 25791.88, filed on 11/12/01, (64) PCT application US 03/11765, filed on 4/16/03, attorney docket no. 25791.89.02, which claims priority from U.S. provisional patent application serial no. 60/383,917, attorney docket no. 25791.89, filed on 5/29/02, (65) PCT application US 03/15020, filed on 5/12/03, attorney docket no. 25791.90.02, which claims priority from U.S. provisional patent application serial no. 60/391,703, attorney docket no. 25791.90, filed on 6/26/02, (66) PCT application US 02/39418, filed on 12/10/02, attorney docket no. 25791.92.02, which claims priority from U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/02, (67) PCT application US 03/06544, filed on 3/4/03, attorney docket no. 25791.93.02, which claims priority from U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/02, (68) U.S. patent application serial no. 10/331,718, attorney docket no. 25791.94, filed on 12/30/02, which is a divisional U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (69) PCT application US 03/04837, filed on 2/29/03, attorney docket no. 25791.95.02, which claims priority from U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/02, (70) U.S. patent application serial no. 10/261,927, attorney docket no. 25791.97, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (71) U.S. patent application serial no. 10/262,008, attorney docket no. 25791.98, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (72) U.S. patent application serial no. 10/261,925, attorney docket no. 25791.99, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (73) U.S. patent application serial no. 10/199,524, attorney docket no. 25791.100, filed on 7/19/02, which is a continuation of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (74) PCT application US 03/10144, filed on 3/28/03, attorney docket no. 25791.101.02, which claims priority from U.S. provisional patent application serial no. 60/372,632, attorney docket no. 25791.101, filed on 4/15/02, (75) U.S. provisional patent application serial no. 60/412,542, attorney docket no. 25791.102, filed on 9/20/02, (76) PCT application US 03/14153, filed on 5/6/03, attorney docket no. 25791.104.02, which claims priority from U.S. provisional patent application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/02, (77) PCT application US 03/19993, filed on 6/24/03, attorney docket no. 25791.106.02, which claims priority from U.S. provisional patent application serial no. 60/397,284, attorney docket no. 25791.106, filed on 7/19/02, (78) PCT application US 03/13787, filed on 5/5/03, attorney docket no. 25791.107.02, which claims

priority from U.S. provisional patent application serial no. 60/387,486, attorney docket no. 25791.107, filed on 6/10/02, (79) PCT application US 03/18530, filed on 6/11/03, attorney docket no. 25791.108.02, which claims priority from U.S. provisional patent application serial no. 60/387,961, attorney docket no. 25791.108, filed on 6/12/02, (80) PCT application US 03/20694, filed on 7/1/03, attorney docket no. 25791.110.02, which claims priority from U.S. provisional patent application serial no. 60/398,061, attorney docket no. 25791.110, filed on 7/24/02, (81) PCT application US 03/20870, filed on 7/2/03, attorney docket no. 25791.111.02, which claims priority from U.S. provisional patent application serial no. 60/399,240, attorney docket no. 25791.111, filed on 7/29/02, (82) U.S. provisional patent application serial no. 60/412,487, attorney docket no. 25791.112, filed on 9/20/02, (83) U.S. provisional patent application serial no. 60/412,488, attorney docket no. 25791.114, filed on 9/20/02, (84) U.S. patent application serial no. 10/280,356, attorney docket no. 25791.115, filed on 10/25/02, which is a continuation of U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (85) U.S. provisional patent application serial no. 60/412,177, attorney docket no. 25791.117, filed on 9/20/02, (86) U.S. provisional patent application serial no. 60/412,653, attorney docket no. 25791.118, filed on 9/20/02, (87) U.S. provisional patent application serial no. 60/405,610, attorney docket no. 25791.119, filed on 8/23/02, (88) U.S. provisional patent application serial no. 60/405,394, attorney docket no. 25791.120, filed on 8/23/02, (89) U.S. provisional patent application serial no. 60/412,544, attorney docket no. 25791.121, filed on 9/20/02, (90) PCT application US 03/24779, filed on 8/8/03, attorney docket no. 25791.125.02, which claims priority from U.S. provisional patent application serial no. 60/407,442, attorney docket no. 25791.125, filed on 8/30/02, (91) U.S. provisional patent application serial no. 60/423,363, attorney docket no. 25791.126, filed on 12/10/02, (92) U.S. provisional patent application serial no. 60/412,196, attorney docket no. 25791.127, filed on 9/20/02, (93) U.S. provisional patent application serial no. 60/412,187, attorney docket no. 25791.128, filed on 9/20/02, (94) U.S. provisional patent application serial no. 60/412,371, attorney docket no. 25791.129, filed on 9/20/02, (95) U.S. patent application serial no. 10/382,325, attorney docket no. 25791.145, filed on 3/5/03, which is a continuation of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (96) U.S. patent application serial no. 10/624,842, attorney docket no. 25791.151, filed on 7/22/03, which is a divisional of U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (97) U.S. provisional patent application serial no. 60/431,184, attorney docket no. 25791.157, filed on 12/5/02, (98) U.S. provisional patent application serial no. 60/448,526, attorney docket no. 25791.185, filed on 2/18/03, (99) U.S. provisional patent application serial no. 60/461,539, attorney docket no. 25791.186, filed on 4/9/03, (100) U.S. provisional patent application serial no. 60/462,750, attorney docket no. 25791.193, filed on 4/14/03, (101) U.S. provisional patent application serial no. 60/436,106, attorney docket no. 25791.200, filed on 12/23/02, (102) U.S. provisional patent application serial no. 60/442,942, attorney docket no. 25791.213, filed on 1/27/03, (103) U.S. provisional patent application serial no. 60/442,938, attorney docket no. 25791.225, filed on 1/27/03, (104) U.S. provisional patent application serial no. 60/418,687, attorney docket no. 25791.228, filed on 4/18/03, (105) U.S. provisional patent application serial no. 60/454,896, attorney docket no. 25791.236, filed on 3/14/03, (106) U.S. provisional patent application serial no. 60/450,504, attorney docket no. 25791.238, filed on 2/26/03, (107) U.S. provisional patent application serial no.



60/451,152, attorney docket no. 25791.239, filed on 3/9/03, (108) U.S. provisional patent application serial no. 60/455,124, attorney docket no. 25791.241, filed on 3/17/03, (109) U.S. provisional patent application serial no. 60/453,678, attorney docket no. 25791.253, filed on 3/11/03, (110) U.S. patent application serial no. 10/421,682, attorney docket no. 25791.256, filed on 4/23/03, which is a continuation of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (111) U.S. provisional patent application serial no. 60/457,965, attorney docket no. 25791.260, filed on 3/27/03, (112) U.S. provisional patent application serial no. 60/455,718, attorney docket no. 25791.262, filed on 3/18/03, (113) U.S. patent number 6,550,821, which was filed as patent application serial no. 09/811,734, filed on 3/19/01, (114) U.S. patent application serial no. 10/436,467, attorney docket no. 25791.268, filed on 5/12/03, which is a continuation of U.S. patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (115) U.S. provisional patent application serial no. 60/459,776, attorney docket no. 25791.270, filed on 4/2/03, (116) U.S. provisional patent application serial no. 60/461,094, attorney docket no. 25791.272, filed on 4/8/03, (117) U.S. provisional patent application serial no. 60/461,038, attorney docket no. 25791.273, filed on 4/7/03, (118) U.S. provisional patent application serial no. 60/463,586, attorney docket no. 25791.277, filed on 4/17/03, (119) U.S. provisional patent application serial no. 60/472,240, attorney docket no. 25791.286, filed on 5/20/03, (120) U.S. patent application serial no. 10/619,285, attorney docket no. 25791.292, filed on 7/14/03, which is a continuation-in-part of U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (121) U.S. utility patent application serial no. 10/418,688, attorney docket no. 25791.257, which was filed on 4/18/03, as a division of U.S. utility patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99; (122) PCT patent application serial no. PCT/US2004/06246, attorney docket no. 25791.238.02, filed on 2/26/2004; (123) PCT patent application serial number PCT/US2004/08170, attorney docket number 25791.40.02, filed on 3/15/04; (124) PCT patent application serial number PCT/US2004/08171, attorney docket number 25791.236.02, filed on 3/15/04; (125) PCT patent application serial number PCT/US2004/08073, attorney docket number 25791.262.02, filed on 3/18/04; (126) PCT patent application serial number PCT/US2004/07711, attorney docket number 25791.253.02, filed on 3/11/2004; (127) PCT patent application serial number PCT/US2004/029025, attorney docket number 25791.260.02, filed on 3/26/2004; (128) PCT patent application serial number PCT/US2004/010317, attorney docket number 25791.270.02, filed on 4/2/2004; (129) PCT patent application serial number PCT/US2004/010712, attorney docket number 25791.272.02, filed on 4/6/2004; (130) PCT patent application serial number PCT/US2004/010762, attorney docket number 25791.273.02, filed on 4/6/2004; (131) PCT patent application serial number PCT/US2004/011973, attorney docket number 25791.277.02, filed on 4/15/2004; (132) U.S. provisional patent application serial number 60/495056, attorney docket number 25791.301, filed on 8/14/2003; (133) U.S. provisional patent application serial number 60/600679, attorney docket number 25791.194, filed on 8/11/2004; (134) PCT patent application serial number PCT/US2005/027318, attorney docket number 25791.329.02, filed on 7/29/2005; (135) PCT patent application serial number PCT/US2005/028936, attorney docket number 25791.338.02, filed on 8/12/2005; (136) PCT patent



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25791.193.03, filed on 10/13/2005; (172) U.S. National Stage application serial no. 10/553566, attorney docket no. 25791.277.06, filed on 10/17/05; (173) PCT Patent Application No. PCT/US2006/\_\_\_\_\_, attorney docket no. 25791.324.02 filed on 1/20/06, and (174) PCT Patent Application No. PCT/US2006/\_\_\_\_\_, attorney docket no. 25791.348.02 filed on 2/9/06; (175) U.S. Utility Patent application serial no. \_\_\_\_\_, attorney docket no. 25791.386, filed on 2/17/06, (176) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.301.06, filed on \_\_\_\_\_, (177) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.137.04, filed on \_\_\_\_\_, (178) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.215.06, filed on \_\_\_\_\_.

[000336] Referring now to Figs. 21a and 21b, a system 2310 for radially expanding a tubular member is illustrated which includes a support member 2312 and an expansion device 2314. In one embodiment, the system 2310 may be used to radially expand and plastically deform a tubular member 2316 by displacing the expansion device 2314 in the longitudinal direction and/or by rotating the expansion device 2314 relative to the tubular member 2316. In an exemplary embodiment, as illustrated in Fig. 21a, expansion is carried out on the tubular member 2316 by displacing the expansion device 2314 through the tubular member 2316 in a direction 2317a. In an exemplary embodiment, as illustrated in Fig. 21b, expansion is carried out on the tubular member 2316 by displacing the expansion device 2314 through the tubular member 2316 in a direction 2317b, which is opposite the direction 2317a, illustrated in Fig. 21a. In an exemplary embodiment, the expansion device 2314 may be adjustable and/or adaptable in order to expand the tubular member 2316.

[000337] Referring now to Figs. 22a and 22b, an exemplary embodiment of an expansion device 2414 is illustrated which may be, for example, the expansion device 2314 illustrated in Figs. 21a and 21b. Expansion device 2414 may include one or more expansion device segments 2418 for engaging, and thereby radially expanding and plastically deforming, a tubular member such as, for example, the tubular member 2316 illustrated in Figs. 21a and 21b. In an exemplary embodiment, expansion device segment 2418 may include a segment of a conventional expansion cone and/or a conventional roller expansion element. As illustrated, expansion device segment 2418 is rotatably coupled to support structure 2420. In turn, support structure 2420 may be coupled to a support member 2421. A cam 2422 may be coupled to expansion device segment 2418 such that it is operable to engage the expansion device segment 2418. In an exemplary embodiment, the cam 2422 laterally supports expansion device segment 2418. A driving mechanism 2424 may be coupled to a motor 2425 and the cam 2422 in order to operate and rotate the cam 2422.

[000338] As illustrated in Figure 22a, expansion device segment 2418 may begin positioned in a first small diameter position  $A_1$ . As illustrated in Figure 22b, the driving mechanism 2424 may be activated by the motor 2425 in order to actuate the cam 2422 and to pivot the expansion device segment 2418 about the support structure 2420 and position the expansion device segment 2418 in a second large diameter position  $A_2$ .

[000339] Referring now to Fig. 23a, a cross sectional view of an exemplary embodiment of the expansion device 2414 of Fig. 22a is illustrated showing the expansion device segment 2418 positioned in the first small diameter position  $A_1$ . The cam 2422 is rotatably coupled off center to the driving mechanism 2424. The cam 2422 is illustrated as having a circular shape, however, the cam 2422 may be of any suitable shape known in the art such as, for example, elliptical, triangular, or irregular.

[000340] As illustrated in Fig. 23a, with the cam 2422 and the expansion device segment 2418 in the first small diameter position  $A_1$ , a distance  $B_1$  between driving mechanism 2424 and expansion device 2418 is minimized. However, as illustrated in Fig. 23b, the cam 2422 may be rotated by the driving mechanism 2424 and into to second

large diameter position  $A_2$  such that a distance  $B_2$  between driving mechanism 2424 and expansion device segment 2418 increases, causing an expansion device segment 2418 to expand in a direction 2426. In an exemplary embodiment, the expansion device 2414 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular member 2316 illustrated in Figs. 21a and 21b.

[000341] Referring now to Fig. 24, an alternative embodiment of an expansion device 2500 is substantially similar in design and operation with the expansion device 2414, described above with reference to Figs. 22a, 22b, 23a, and 23b, with the provision of a controller 2534 operably coupled to the motor 2525. The controller 2534 may also be in communication with one or more sensors 2536. A user interface 2538 may also be provided which may be in operable communication with controller 2534.

[000342] In an exemplary embodiment, the controller 2534 includes analog, digital, electronic, and/or hydraulic control elements that may be positioned within or coupled to expansion device 2500. In an exemplary embodiment, the user interface 2538 may include a conventional keyboard input device and/or a conventional display device and/or a conventional communication channel for linking the user interface 2538 to the controller 2534.

[000343] In an exemplary embodiment, during the operation of expansion device 2500, the controller 2534 is programmed to adjust the rotation of the cam 2422 as a function of one or more operating conditions that are sensed by the sensors 2536. In an exemplary embodiment, the sensed operating conditions sensed by the sensors 2536 may include the reaction forces of a tubular member such as, for example, the tubular member 2316 illustrated in Fig. 21a, the operating pressure of fluidic materials within a system and/or the tubular member such as, for example, the system 2310 and/or the tubular member 2316 illustrated in Fig. 21a, the rotational speed of a system such as, for example, the system 2310 illustrated in Fig. 21a, the longitudinal speed of a system such as, for example, the system 2310 illustrated in Fig. 21a, and/or one or more user defined inputs to the controller 2534 provided via the user interface 2538.

[000344] In an exemplary embodiment, at least one of the sensors 2536 includes a conventional strain gauge that senses the reaction force of a tubular member such as, for example, the tubular member 2316 illustrated in Fig. 21a, during the radial expansion and plastic deformation of the tubular member by a system such as, for example, the system 2310 illustrated in Fig. 21a. In an exemplary embodiment, increases in the sensed reaction force causes the controller 2534 to change the rotation of the cam 2422, thereby increasing or decreasing the lateral expansion position of the expansion device segment 2418. In this manner, the forces applied to a tubular member such as, for example, the tubular member 2316 illustrated in Fig. 21a, may be increased or decreased for example, to provide increased or decreased radial expansion forces as a function of the sensed reaction forces.

[000345] In an exemplary embodiment, at least one of the sensors 2536 includes a conventional pressure sensor that senses the operating pressures of fluidic materials within a system and/or tubular member such as, for example, the system 2310 and the tubular member 2316 illustrated in Fig. 21a, during the radial expansion and plastic deformation of the tubular member by the system. In an exemplary embodiment, the value of the sensed operating pressure causes the controller 2534 to rotate the cam 2422 to increase or decrease the stiffness of corresponding expansion device segments 2418. In this manner, the forces applied to a tubular member such as, for example, the tubular member 2316 illustrated in Fig. 21a, may be increased or decreased for example, to provide increased or decreased radial expansion forces as a function of the sensed operating pressures.

[000346] In an exemplary embodiment, the controller 2534 is programmed to adaptively adjust the rotation of one or more cams 2422, which in turn adjusts the lateral position of respective expansion device segments 2418. In this manner, a system such as, for example, the system 2310 illustrated in Fig. 21a, can provide an adaptive

expansion system having user defined operational characteristics that may vary as a function of one or more sensed operating conditions. In an exemplary embodiment, the expansion device 2500 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular member 2316 illustrated in Figs. 21a and 21b.

[000347] Referring to Figs. 21a, 24, and 25a, in an exemplary embodiment, the tubular member 2310 is positioned adjacent to and partially within a tubular member 2600. The system 2310 is then used to radially expand and plastically deform the tubular member 2316 into overlapping engagement with the tubular member 2600. In an exemplary embodiment, during the radial expansion and plastic deformation of tubular member 2316 into overlapping engagement with the tubular member 2600, the reaction forces of overlapping ends of the tubular members 2316 and 2600 are sensed by one or more of the sensors 2536 and, if the sensed reaction forces increase, the cam 2422 may be rotated to laterally adjust respective expansion device segment 2418 to thereby increase or decrease the radial expansion forces applied to the overlapping ends of the tubular members 2316 and 2600. In this manner, the system 2310 can controllably adjust the radial expansion forces applied to overlapping tubular members thereby enhancing the radial expansion process. In an exemplary embodiment, the location of the overlapped ends of the tubular members 2316 and 2600 may be input into the controller 2534 using the user interface 2538 to control the rotation of the cam 2422, and therefore the lateral position of respective expansion device segment 2418 in combination with, or in the alternative to, the sensing of the reaction forces described above.

[000348] Referring again to Fig. 25a, in an exemplary embodiment, a force is applied to the support member 2312 in the direction 2317a, which results in the expansion device 2314 being displaced in the direction 2317a. The movement of expansion device 2314 in the direction 2317a causes the end of tubular member 2316 to expand into engagement with the end of tubular member 2600.

[000349] Referring now to Figs. 24 and 25b, in an exemplary embodiment, the system 2310 is used to radially expand and plastically deform a tubular member assembly including a first tubular member section 2700a and a second tubular member section 2700b which are coupled to each other by a threaded connection 2702. In an exemplary embodiment, during the radial expansion and plastic deformation of the threaded connection 2702, the reaction forces of the threaded connection 2702 are sensed by one or more of the sensors 2536 and the rotation of the cam 2422, which may be associated with the one or more expansion device segments 2418 of expansion device 2314, is adjusted to thereby minimize damage to the integrity of the threaded connection 2702 during the radial expansion process. For example, the rotation of the cam 2422 may be adjusted to reduce the lateral position of the expansion device segment 2418 to minimize damage to the integrity of the threaded connection 2702 during the radial expansion process. In an alternative embodiment, the location of the threaded connection 2702 may be input into the controller 2534 using the user interface 2538 to control the initiation of the adjustment of the cam 2422 and the lateral position of respective expansion device segments 2418 in combination with, or in the alternative to, the sensing of the reaction forces described above.

[000350] Referring again to Fig. 25b, in an exemplary embodiment, a force is applied to the support member 2312 in the direction 2317a, which displaces the expansion device 2314 in the direction 2317a and through the tubular member sections 2700a and 2700b, expanding the tubular member sections 2700a and 2700b and the threaded connection 2702.

[000351] Referring to Figs. 24 and 25c, in an exemplary embodiment, the system 2310 is used to radially expand and elastically deform a subterranean formation 2800 during the radial expansion and plastic deformation of the tubular member 2316. In one embodiment, during the radial expansion and plastic deformation of the tubular



member 2316 against the subterranean formation 2800, the reaction forces of the subterranean formation 2800 are sensed by one or more of the sensors 2536, and the rotation of the cam 2422 and the lateral position of expansion device segment 2418 of expansion device 2314 are increased to thereby increase the radial expansion forces applied to the subterranean formation 2800. In this manner, the system 2310 can controllably adjust the radial expansion forces applied to the subterranean formation 2800 surrounding the tubular member 2316 during the radial expansion and plastic deformation of the tubular member 2316. In an alternative embodiment, the location of the subterranean formation 2800 may be input into the controller 2534 using the user interface 2538 to control the rotation of the cam 2422 in combination with, or in the alternative to, the sensing of the reaction forces described above.

[000352] Referring again to Fig. 25c, in an exemplary embodiment, a force is applied to the support member 2312 in the direction 2317a, which displaces the expansion device 2314 in the direction 2317a, through the tubular member 2316. The displacement of the expansion device 2314 in the direction 2317a causes the tubular member 2316 to expand into engagement with the subterranean formation 2800.

[000353] More generally, the expansion devices 2314 and 2500 illustrated in Figs. 24 and 25a illustrate that the operational characteristics of the expansion devices 2314 and 2500 may be determined as a function of empirical data regarding the tubular member 2316 which is determined during a radial expansion testing procedure. For example, if a certain rotation of the cam 2422 for one or more of expansion device segments 2418 provides enhanced operational performance of the tubular member 2316 before, during, or after a radial expansion and plastic deformation of the tubular member 2316, then the preferred rotation of the cam 2422, or the range and/or variation in the rotation of the cam 2422, may be programmed into the controller 2534 to thereby provide enhanced radial expansion and plastic deformation of the tubular member 2316 using the expansion devices 2314 and/or 2500.

[000354] Referring now to Fig. 26a, an alternative embodiment of an expansion device 2900 is substantially similar in design and operation to the expansion devices 2414 and 2500, described above with reference to Figs. 22a, 22b, and 24, with the provision of a expansion segment 2902 engaging the cam 2422 and pivotally coupled to a support structure 2904 which is mounted to a support member 2906 and positioned opposite the expansion segment 2418.

[000355] Referring now to Figs. 26a and 26b, the expansion device segments 2418 and 2902 begin in a first small diameter position  $C_1$ . The motor 2425 may then activate the driving mechanism 2424 in order to actuate the cam 2422 and move the expansion device segments 2418 and 2902 into a second large diameter position  $C_2$ . In an exemplary embodiment, expansion device segments 2418 and 2902 may include segments of a conventional expansion cone and/or conventional roller expansion elements. The cam 2422 may be movably coupled to expansion device segments 2418 and 2902. In an exemplary embodiment, the cam 2422 laterally supports the expansion device segments 2418 and 2902. The driving mechanism 2424 may be coupled to the cam 2422 in order to operate and rotate the cam 2422.

[000356] Referring now to Fig. 27a, in an exemplary embodiment, the cam 2422 is elliptically shaped and positioned adjacent the expansion device segments 2418 and 2902 and rotated such that the expansion device segments 2418 and 2902 are in the first small diameter position  $C_1$ . In an exemplary embodiment, the cam 2422 may be of any suitable shape known in the art such as, for example, triangular or irregular. In an exemplary embodiment, a distance 2908 between the center of the cam 2422 and the expansion device segments 2418 and 2902 is minimized when the expansion device segments 2418 and 2902 are in the first small diameter position  $C_1$ . In response to the cam 2422 being rotated about the driving mechanism 2424, the distance between the center of the

cam 2422 and the expansion device segments 2418 and 2902 increases to a maximum distance 2910 when the expansion device segments 2418 and 2902 are in the second large diameter position  $C_2$ , as illustrated in Fig. 27b, causing the expansion device segments 2418 and 2902 to expand in a lateral direction 2912. In an exemplary embodiment, the expansion device 2900 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, and 2700b illustrated in Figs. 21a, 21b, 25a, 25b, and 25c.

[000357] Referring now to Figs. 28 and 28a, an alternative embodiment of an expansion device 3000 is substantially similar in design and operation to the expansion device 2900, described above with reference to Figs. 26a, 26b, 27a, and 27b, with the provision of a plurality of expansion device segments 3002a and 3002b interlaced with the expansion device segments 2418 and 2902. A secondary cam 3004 is coupled to the cam 2422 and the expansion device segments 3002a and 3002b engage the secondary cam 3004 while being pivotally coupled to a plurality of support structures 3006a and 3006b, respectively, which are mounted to a plurality of support members 3008a and 3008b, respectively. The expansion device segments 3002a and 3002b may include segment of a conventional expansion cone and/or a conventional roller expansion element. In an exemplary embodiment, cam 2422 laterally supports expansion device segments 2418 and 2902 and cam 3004 laterally supports expansion device segments 3002a and 3002b.

[000358] Referring again to Figs. 28 and 28a, in an exemplary embodiment, expansion device segments 2418, 2902, 3002a, and 3002b are all radially aligned about an axis of the driving mechanism 2424.

[000359] Referring now to Figs. 28, 28a, 29a, and 29b, in an exemplary embodiment, the expansion device segments 2418 are aligned as illustrated in Fig. 29a, and the expansion device segments 3002a and 3002b are positioned rotated 90° about an axis of the driving mechanism 2424 relative to expansion device segments 2902, as illustrated in Fig. 29b. The positioning illustrated in Figs. 29a and 29b allows the expansion device segments 2418 and 2902 to cover about one half of an inner circumference of a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b, and allows the expansion device segments 3002a and 3002b to cover the remaining one half of the inner circumference of the tubular member.

[000360] Referring now to Figs. 29a and 29b, the cams 2424 and 3004 are in a first small diameter position  $D_1$  in which a distance 3010a between the center of cam 2424 and the expansion devices 2418 and 2902 is minimized, and a distance 3010b between the center of cam 3004 and the expansion devices 3002a and 3002b is minimized. As illustrated, the long axis of cams 2424 and 3004 are orientated perpendicular to each other. The cams 2422 and 3004 may then be rotated to a second large diameter position  $D_2$ , illustrated in Figs. 29c and 29d, such that a distance 3012a between the center of cam 2422 and expansion device segments 2418 and 2902 substantially increases, causing expansion device segments 2418 and 2902 to laterally expand. Rotation of the cams 2424 and 3004 to a second large diameter position  $D_2$  also results in a distance 3012b between the center of cam 3004 and the expansion device segments 3002a and 3002b substantially increasing, causing expansion device segments 3002a and 3002b to laterally expand. Cams 2424 and 3004 may be independently controlled, thereby allowing one set of expansion device segments to exert a greater lateral force than the other set of expansion devices, or control together with one driving mechanism. In an exemplary embodiment, the expansion device 300 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, and 2700b illustrated in Figs. 21a, 21b, 25a, 25b, and 25c.

[000361] Referring now to Fig. 29e, in an exemplary embodiment, the cam 2422 and its corresponding expansion device segments 2418 and 2902 may be offset from and positioned above the cam 3004 and its corresponding expansion device segments 3002a and 3002b. As illustrated, the long axis of cams 2424 and 3004 are orientated perpendicular to each other. In an exemplary embodiment, the cams 2424 and 3004 may be independently controlled, thereby allowing one set of expansion device segments to exert a greater lateral force than the other set of expansion devices. In an exemplary embodiment, the cams 2424 and 3004 may be jointly controlled by driving mechanism 2424.

[000362] As illustrated, expansion device segment 2418 has an arc angle  $E_1$  of approximately  $90^\circ$ , expansion device segment 3002b has an arc angle  $E_2$  of approximately  $90^\circ$ , expansion device segment 2902 has an arc angle  $E_3$  of approximately  $90^\circ$ , and expansion device segment 3002a has an arc angle  $E_4$  of approximately  $90^\circ$ . As shown, arc angles  $E_1$ ,  $E_2$ ,  $E_3$ , and  $E_4$  add up to about  $360^\circ$ , with no significant overlap.

[000363] In an alternative embodiment, each of arc angles  $E_1$ ,  $E_2$ ,  $E_3$ , and  $E_4$  is about  $120^\circ$  to  $150^\circ$  such that portions of expansion device segments 2418 and 2902 circumferentially overlap with portions of expansion device segments 3002a and 3002b. However, there is no interference since expansion device segments 2418 and 2902 are vertically spaced or offset from segments 3002a and 3002b.

[000364] In an exemplary embodiment, expansion device segments 2418 and 2902 may be pushed and/or pulled through a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b, in an expanded condition such that a section of cylindrical tubular member is expanded into an elliptical shape. Expansion device segments 3002a and 3002b may then be pushed and/or pulled through the same section of the tubular member, whereby expansion device segments 3002a and 3002b are offset or rotated about  $90^\circ$  from expansion device segments 2418 and 2902 in order to expand the section of the tubular member from an elliptical shape into a circular shape.

[000365] Referring now to Figs. 30a and 30c, an alternative embodiment of an expansion device 3100 is substantially similar in design and operation to the expansion device 2900, described above with reference to Figs. 26a and 26b, with the provision of a plurality of support structures 3102a and 3102b replacing the support structures 2420 and 2904 which allow the expansion device segments 2418 and 2902 to translate laterally as opposed to pivoting. The expansion device segments 2418 and 2902 are operable to engage and thereby radially expand and plastically deform a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b. In an exemplary embodiment, expansion device segments 2418 and 2902 may include segments of a conventional expansion cone and/or a conventional roller expansion elements. The cam 2422 may be coupled to the expansion device segments 2418 and 2902 in a manner previously described. In an exemplary embodiment, the cam 2422 laterally supports the expansion device segments 2418 and 2902. The driving mechanism 2424 may be coupled to the cam 2422 in order to operate and rotate the cam 2424.

[000366] In operation, expansion device segments 2418 and 2902 begin proximate to the longitudinal sides of the cam 2424, positioning the expansion device 3100 in a first small diameter position  $F_1$ , illustrated in Figs. 30a and 30c. In first small diameter position  $F_1$ , the distance between the center of driving mechanism 2424 and expansion device segments 2418 and 2902 is minimized. The cam 2422 may then be rotated through the driving mechanism 2424 by the motor 2425 in order to cause expansion device segments 2418 and 2902 to translate outward, positioning expansion device 3100 in a second large diameter position  $F_2$ , illustrated in Figs. 30b and 30d, which increases the distance between the center of the driving mechanism 2424 and expansion device segments

2418 and 2902 and causes the expansion device 3100 to expand in a lateral direction. Support structures 3102a and 3102b allow for a lateral translation while supporting expansion device segments 2418 and 2902 longitudinally. In an exemplary embodiment, the expansion device 3100 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, and 2700b illustrated in Figs. 21a, 21b, 25a, 25b, and 25c.

[000367] Referring now to Fig. 31a, an alternative embodiment of an expansion device 3200 is substantially similar in design and operation to the expansion device 3100, described above with reference to Figs. 30a and 30b, with provision of a plurality of collets 3202a and 3202b coupled together by a mandrel 3204 which replaces the cam 2422. The collet 3202a includes a plurality of opposing wedged surfaces 3202aa and 3202ab and the collet 3202b includes a plurality of opposing wedged surface 3202ba and 3202bb. Expansion device segment 2418 is provided with a plurality of opposing surfaces 3206a and 3206b and expansion device segment 2902 is provided with a plurality of opposing surfaces 3208a and 3208b. A motor 3210 is provided and coupled to the collets 3202a and 3202b and the mandrel 3204 by a driving mechanism 3212 and is positioned opposite the motor 2425 and the driving mechanism 2424, which are also coupled to the collets 3202a and 3202b and the mandrel 3204. The motors 2425 and 3210 are operable to move the collets 3202a and 3202b towards each other on the mandrel 3204. Expansion device 3200 is operable to engage and thereby radially expand and plastically deform a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b. In an exemplary embodiment, the expansion device segments 2418 and 2902 may include segments of a conventional expansion cone and/or conventional roller expansion elements. As illustrated, expansion device segments 2418 and 2902 are coupled to the support structures 3102a and 3102b, respectively, which allow lateral translation of the expansion device segments 2418 and 2902. The two collets 3202a and 3202b are positioned facing each other along the mandrel 3204. In an exemplary embodiment, the collets 3202a and 3202b are generally cone or wedged shaped and are coupled to expansion device segments 2418 and 2902 such that, as collets 3202a and 3202b move relative to each other longitudinally, the expansion device segments 2418 and 2902 move laterally relative to each other. For example, as the collet 3202a moves along the mandrel 3204 and towards the collet 3202b, wedged surfaces 3202aa and 3202ab of collet 3202a engage surfaces 3606a and 3808a, respectively, on engagement device segment 2418, and wedged surfaces 3202ba and 3202bb of collet 3202b engage surfaces 3606b and 3808b, respectively, on engagement device segment 2902, driving the expansion device segments 2418 and 2902 apart in a lateral direction as illustrated in Fig. 31b.

[000368] In operation, the collets 3202a and 3202b begin at a maximum longitudinal distance from each other, as illustrated in Fig. 31a, with expansion device segments 2418 and 2902 positioned relatively close to each other such that expansion device 3200 is in a first small diameter position  $G_1$ . The motors 2425 and 3210 may then be actuated to move the collets 3202a and 3202b to a minimum longitudinal distance from each other, as illustrated in Fig. 31b, such that expansion device segments 2418 and 2902 are in a second large diameter position  $G_2$ . The support structures 3102a and 3102b allow for a lateral translation of the expansion device segments 2418 and 2902 while supporting the expansion device segments 2418 and 2902 longitudinally. In an exemplary embodiment, the expansion device 3200 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, and 2700b illustrated in Figs. 21a, 21b, 25a, 25b, and 25c.

[000369] Referring now to Fig. 32, an expansion device 3300 is illustrated. Expansion device 3300 includes a top expansion device 3302a and bottom expansion device 3302b which are coupled together by an intervening support member 3304 and positioned within a tubular member 3305. The top expansion device 3302a is coupled to



a support member 3306. A bottom cup seal 3308 and a top cup seal 3310 are coupled to the support member 3306 and positioned spaced apart and above the top expansion member 3302a. In operation, a relatively large pressure may be applied to an annular region 3312 within the tubular member 3305 and a relatively small pressure may be applied to an annular region 3314 within the tubular member 3305, which results in a pressure differential that applies a force to the bottom cup seal 3308 and the top cup seal 3310 in a direction 3316. This force is translated from the bottom cup seal 3308 and the top cup seal 3310 to the support member 3306, which pulls top expansion device 3302a, the intervening support member 3304, and bottom expansion device 3302b in the direction 3316 and may result in the expansion of the tubular member 3305 when the top expansion device 3302a and the bottom expansion device 3302b are expanded such as, for example, in a manner described above with reference to the expansion devices 2314, 2414, 2500, 2900, 3000, 3100, and 3200. In an exemplary embodiment, the expansion device 3300 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, and 2700b illustrated in Figs. 21a, 21b, 25a, 25b, and 25c.

[000370] Referring now to Fig. 33a, an exemplary embodiment of an expansion device 3400 is illustrated. Expansion device 3400 includes an expansion device 3402 with an angled edge 3402a and which is coupled to support member 3404 and positioned within a tubular member 3406 which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b. The tubular member 3406 is located in a wellbore 3408 which includes a wellbore casing 3310 which engages the walls of the wellbore 3408. The tubular member 3406 also includes an expansion sleeve 3412 positioned within the tubular member 3406 and a seal 3414 positioned adjacent an end 3416 of the tubular member 3406 and on an outer surface of the tubular member 3406. In operation, as illustrated in Figs. 33a and 33b, the support member 3404 pulls the expansion device 3402 in a direction 3416, resulting in the angled edge 3402a of expansion device 3402 engaging the expansion sleeve 3412. Upon engagement, the expansion sleeve 3412 plastically deforms around the angled edge 3402a of the expansion device 3402 due to the inside diameter of expansion sleeve 3412 being smaller than the outside diameter of expansion device 3402, and the expansion sleeve 3412 couples to the angled edge 3402a of the expansion device 3402. Engagement of the expansion sleeve 3412 and the expansion device 3402 provides the expansion device 3402 with a large enough diameter to expand the tubular member 3406, as illustrated in Fig. 33b.

[000371] As the expansion device 3402 begins its engagement with expansion sleeve 3412, the expansion sleeve 3412 may be attached to tubular member 3406. After the engagement, the expansion sleeve 3412 detaches from the tubular member 3406 and begins to travel through the tubular member 3406 with the expansion device 3402. In an exemplary embodiment, expansion sleeve 3412 may be attached to tubular member 3406 with shear pins.

[000372] In an exemplary embodiment, the expansion device 3402 has a fixed diameter, such that the expansion device 3402 may be placed in the wellbore 3408 prior to placing the expansion sleeve 3412 in the wellbore 3408 such as, for example, when the expansion device 3402 is used to expand the tubular member 3416 when traveling in direction 3416. In an exemplary embodiment, the expansion device 3402 has a diameter that may vary from a small diameter configuration to a large diameter configuration, such that the expansion sleeve 3412 may be placed in the wellbore 3408 before the expansion device 3402 is fed through the tubular member 3406 and the expansion sleeve 3412 in small diameter configuration. The expansion device 3402 may then be expanded from the small diameter configuration to the large diameter configuration, where the large diameter configuration is larger than the inside diameter of the expansion sleeve 3412. In an exemplary embodiment, the expansion device 3400 may be adjustable

and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, 2700b, and 3406 illustrated in Figs. 21a, 21b, 25a, 25b, 25c, 33a, and 33b.

[000373] Referring now to Figs. 34a, 34b, 34c, and 34d, an alternative embodiment of an expansion device 3500 is substantially similar in design and operation to the expansion device 2414, described above with reference to Figs. 22a and 22b, with provision of an expansion device roller 3502 which is rotatably coupled to an axle 3504 which extends from either end of the roller 3502 and which couples the roller 3502 to the structure support 2420. In an exemplary embodiment, expansion device 3500 may include one or more expansion device rollers 3502 for engaging, and thereby radially expanding and plastically deforming a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b. In an exemplary embodiment, expansion device roller 3502 may include a roller of a conventional roller expansion element. The cam 2422 is movably coupled to an end of the axle 3504. In an exemplary embodiment, the cam 2422 laterally supports the axle 3504. The driving mechanism 2424 is coupled to the cam 2422 and operable to operate and rotate the cam 2422. The cam 2422 may be of any suitable shape, including circular, elliptical, triangular, or irregular.

[000374] Referring now to Figs. 34a, 34b, 34c, and 34d, in operation, the expansion device 3500 begins in a first small diameter position  $H_1$ , as illustrated in Figs. 34a and 34c. The cam 2422 may then be rotated through the driving mechanism 2424 by the motor 2425, whereby the engagement of the cam 2422 with the axle 3504 places the expansion device 3500 in a second large diameter position  $H_2$ , as illustrated in Figs. 34b and 34d. Rotating the cam 2422 causes the expansion device roller 3502 to expand laterally. Although the expansion device roller 3502 is shown with a cylindrical shape, the expansion device roller 3502 may be of any suitable shape known in the art such as, for example barrel-shaped, conical, and/or frustoconical. In an exemplary embodiment, there may also be provided suitable bearings and/or lubricants and/or seals between expansion device roller 3502 and the axle 3504. In an exemplary embodiment, the expansion device 3500 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, 2700b, and 3406 illustrated in Figs. 21a, 21b, 25a, 25b, 25c, 33a, and 33b.

[000375] Referring now to Figs. 35a and 35c, an alternative embodiment of an expansion device 3600 is substantially similar in design and operation to the expansion device 3100, described above with reference to Figs. 30a and 30b, with the provision of a plurality of expansion member rollers 3602a and 3602b replacing the expansion member sections 2418 and 2902. Expansion member roller 3602a is rotatably coupled to an axle 3604 which extends from either end of the expansion member roller 3602a and which is coupled to the support structures 3102a and 3102b, the cam 2422, and a cam 3606 which is coupled to the driving mechanism 2424. Expansion member roller 3602b is rotatably coupled to an axle 3608 which extends from either end of the expansion member roller 3602b and which is coupled to the support structures 3102a and 3102b, the cam 2422, and the cam 3606. The expansion device 3600 may include one or more expansion device rollers 3602a and 3602b for engaging, and thereby radially expanding and plastically deforming, a tubular member. In an exemplary embodiment, expansion device rollers 3602a and 3602b may include conventional roller expansion elements. In an exemplary embodiment, the cams 3606 and 2422 laterally support the axles 3604 and 3608. The driving mechanism 2424 may be coupled to the cams 3606 and 2422 and operable to operate and rotate the cams 3606 and 2422.

[000376] Referring now to Figs. 35a, 35b, 35c, and 35d, in operation, the expansion device rollers 3602a and 3602b begin proximate to the longitudinal sides of cams 3606 and 2422 such that the expansion device 3600 is in a first small diameter position  $I_1$ , illustrated in Figs. 35a and 35c, in which the distance between the center of the

driving mechanism 2424 and expansion device rollers 3602a and 3602b is minimized. The cams 3606 and 2422 may then be rotated such that their engagement with the axles 3604 and 3608 causes the expansion device 3600 to be positioned in a second large diameter position  $I_2$ , illustrated in Figs. 35b and 35d, in which the distance between the center of the driving mechanism 2424 and the expansion device rollers 3602a and 3602b substantially increases, causing expansion device rollers 3602a and 3602b to expand in a lateral direction. The support structures 3102a and 3102b allow for a lateral translation while supporting axles 3602a and 3602b and expansion device rollers 3602a and 3602b longitudinally.

[000377] In an exemplary embodiment, there may also be provided suitable bearings and/or lubricants and/or seals between the expansion device rollers 3602a and 3602b and the axles 3602a and 3602b. In an exemplary embodiment, the expansion device 3600 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, 2700b, and 3406 illustrated in Figs. 21a, 21b, 25a, 25b, 25c, 33a, and 33b.

[000378] Referring now to Fig. 36a, an alternative embodiment of an expansion device 3700 is substantially similar in design and operation to the expansion device 3600 described above with reference to Figs. 35a and 35b with the provision of a plurality of piston actuation structures 3702a and 3702b replacing the support structures 3102a and 3102b and the cams 3606 and 2422. The piston actuation structures 3702a and 3702b are coupled to and actuated by the driving mechanism 2424, with piston actuation structure 3702a including a rod 3702aa coupled to axle 3604 and a rod 3702ab coupled to axle 3608, and piston actuation structure 3702b including a rod 3702ba coupled to axle 3604 and a rod 3702bb coupled to axle 3608. The expansion device 3700 may include one or more expansion device rollers 3602a and 3602b for engaging, and thereby radially expanding and plastically deforming, a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b. In an exemplary embodiment, expansion device rollers 3602a and 3602b may include conventional roller expansion elements. Piston actuation structures 3702a and 3702b may include conventional piston-type actuators known in the art.

[000379] Referring now to Figs. 36a and 36b, in operation, rods 3702aa and 3702ab on piston actuation structure 3702a and rods 3702ba and 3702bb on piston actuation structure 3702b are retracted, resulting in the expansion device rollers 3602a and 3602b being positioned adjacent the piston actuation structures 3702a and 3702ba and the expansion device 3700 being positioned in a first small diameter position  $J_1$ , as illustrated in Fig. 36a, in which the distance between the center of driving mechanism 2424 and the expansion device rollers 3602a and 3602b is minimized. Piston actuations structures 3702a and 3702b may then be actuated which translates the axles 3604 and 3608 outward such that the expansion device rollers 3602a and 3602b are extended away from the driving mechanism 2424 and the expansion device 3700 is positioned in a second large diameter position  $J_2$ , as illustrated in Fig. 36b, in which the distance between the center of driving mechanism 2424 and expansion device rollers 3602a and 3602b substantially increases. Piston actuations structures 3702a and 3702b allow for a lateral translation of the expansion device rollers 3602a and 3602b while supporting the axles 3604 and 3608 and the expansion device rollers 3602a and 3602b longitudinally.

[000380] In an exemplary embodiment, the piston actuations structures 3702a and 3702b may be operated by using a pressurized gas or fluid. The pressure of the pressurized gas or fluid may be adjusted to exert a specific force on expansion device rollers 3602a and 3602b. The predetermined pressure and force can be constant throughout an expansion process, or variable depending on what section of the tubular member is being expanded.

For example, a larger pressure and force may be desired in the middle of the tubular member, but a smaller pressure and force may be desired at an end of the tubular member such as, for example, adjacent a threaded connections.

[000381] In another embodiment, there may also be provided suitable bearings and/or lubricants and/or seals between expansion device rollers 3602a and 3602b and axles 3604 and 3608. In an exemplary embodiment, the expansion device 3600 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, 2700b, and 3406 illustrated in Figs. 21a, 21b, 25a, 25b, 25c, 33a, and 33b.

[000382] Referring now to Figs. 37a and 37b, an exemplary embodiment of an expansion system 3800 is illustrated. Expansion system 3800 includes an expansion device 3802 which is coupled to a support member 3803. Expansion device 3802 includes a flexible metal skin 3804, a plurality of inserts 3806, and a bladder 3808 which is coupled to the support member 3803 such that a pressurized fluid or gas may be fed through the support member 3803 and into the bladder 3808 in order to expand the expansion device 3802. When the bladder 3808 is not filled with pressurized fluid or gas, the expansion device 3802 has a retracted configuration  $K_1$ , as illustrated in Figs. 37a and 37b.

[000383] Referring now to Figs. 38a and 38b, in operation, the bladder 3802 may be filled with pressurized fluid or gas which may be fed through the support member 3803 in order to place the expansion device 3802 into an expanded configuration  $K_2$ , as illustrated in Figs. 38a and 38b. The expansion system 3800 may then be displaced through a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b, in order to expand and plastically deform the tubular member. The inserts 3806 may provide a durable point of contact for the expansion device 3802 as it is used to expand and plastically deform the tubular member.

[000384] The Inserts 3806 may be made of a hard material, for example a metal carbide, a diamond, a tool steel, or other suitable materials used for tool inserts. In an exemplary embodiment, the expansion device 3802 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, 2700b, and 3406 illustrated in Figs. 21a, 21b, 25a, 25b, 25c, 33a, and 33b.

[000385] Referring now to Figs. 39a, 39b, and 39c, an exemplary embodiment of an expansion device 3900 is illustrated. Expansion device 3900 includes an expandable member 3902 and a support mandrel 3903. Expandable member 3902 includes a first large section 3904, a second large section 3906, a third large section 3908, a first small section 3910, a second small section 3912, and a third small section 3914. Although illustrated with three large sections and three small sections, in an exemplary embodiment the number of small sections can vary from about 2 to about 10, and the number of large sections can vary from about 2 to about 10. In an exemplary embodiment, the number of small sections can vary from about 3 to about 5, and the number of large sections can vary from about 3 to about 5.

[000386] In operation, the expansion member 3902 may be placed within a retaining sleeve 3918 to hold the expansion member 3902 in a collapsed configuration  $L_1$ . To collapse expansion member 3902, support mandrel 3903 is removed from within expansion device 3902. Each of first large section 3904, second large section 3906, third large section 3908, first small section 3910, second small section 3912, and third small section 3914 may be cantilevered or pivotally mounted to a section retainer and, after support mandrel 3916 is removed, each of first large section 3904, second large section 3906, third large section 3908, first small section 3910, second small section 3912, and third small section 3914 will collapse into the collapsed configuration  $L_1$  on their own, allowing expansion member 3902 to be pushed and/or pulled through a small opening.



[000387] The support mandrel 3903 may then be centrally positioned within the expansion member 3902 to support first large section 3904, second large section 3906, third large section 3908, first small section 3910, second small section 3912, and third small section 3914. The expansion device 3900 may then be displaced through a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b, in order to radially expand and plastically deform the tubular member.

[000388] To expand expansion member 3902, retaining sleeve 3918 is removed, and support mandrel 3903 is forced within first small section 3910, second small section 3912, and third small section 3914, which small sections 3910, 3912, and 3914 then engage first large section 3904, second large section 3906, third large section 3908, in order to place the expansion device 3900 in an expanded configuration  $L_2$ , as illustrated in Figs. 39b and 39b. In an exemplary embodiment, the expansion device 3900 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, 2700b, and 3406 illustrated in Figs. 21a, 21b, 25a, 25b, 25c, 33a, and 33b.

[000389] Referring now to Figs. 40a, 40b, and 40c, an exemplary embodiment of an expansion member 4000 is illustrated. Expansion member 4000 includes an expansion device 4002 which may be used to radially expand and plastically deform a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b. Expansion device 4002 includes a cam 4004 and a plurality of expansion segments 4006 positioned about the perimeter of the cam 4004. Each expansion segments 4006 includes a leading edge 4008 and trailing edge 4010. At each leading edge 4008 is groove 4012, and at each trailing edge 4010 is key 4014. Although the expansion device 4002 is shown with six expansion segments, the number of expansion segments can be between about 3 to about 30 in one embodiment, and between about 5 and about 10 in another embodiment, with a suitably shaped cam in each embodiment.

[000390] Referring now to Fig. 40c, the key 4014 and the groove 4012 are operable to slidingly engage. Each key 4014 on trailing edge 4010 of each expansion segment 4006 is adapted to slide within each groove 4012 on leading edge 4008 of adjacent expansion segment 4006. Each groove 4012 has stops at each end to prevent key 4014 from leaving groove 4012 and disengaging adjacent expansion segments 4006.

[000391] Referring now to Fig. 40a, in operation, the expansion device 4002 begins in a collapsed configuration  $M_1$ , as illustrated in Fig. 40a. Each expansion segment 4006 may overlap with adjacent expansion segments 4006. Each expansion segment 4006 is operable to collapse into the collapsed configuration  $M_1$ , as illustrated in Fig. 40a, on their own, when expansion device 4002 is pushed and/or pulled through a small opening and/or when a retaining sleeve or similar device known in the art is forced over expansion device 4002.

[000392] Referring now to Fig. 40b, the cam 4004 may be rotated, which forces expansion segments 4006 from their overlapping configuration into an expanded configuration  $M_2$ , as illustrated in Fig. 40b. In an exemplary embodiment, the expansion device 4002 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, 2700b, and 3406 illustrated in Figs. 21a, 21b, 25a, 25b, 25c, 33a, and 33b.

[000393] Referring now to Fig. 41a, an expansion system 4100 is illustrated. Expansion system 4100 includes an expansion device 4102 having an outer expansion surface 4102a and including a laser cladded coating 4104 on the outer expansion surface 4102a which may be applied to the expansion device 4102 using methods for laser cladding known in the art. The laser cladded coating 4104 includes a wear resistant material and is of a thickness 4104a which are sufficient to impart a strength, toughness, and bond strength to the expansion device 4102 and a hardness in order to expand a tubular member which may be, for example, the tubular members 2316, 2600, or

2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b, by displacing the expansion system 4100 through the tubular member at a controlled rate. The material for the laser cladded coating 4104 and the expansion device 4102, the angle of the outer expansion surface 4102a, and the dimensions and geometry of the expansion device 4102 may be selected to minimize friction and tendency to gall. The expansion device 4102 may include a variety of materials known in the art which are of sufficient strength and ductility to support the laser cladded coating 4104 during operation such as, for example, low alloy steels. In an exemplary embodiment, as illustrated in Fig. 41b, the laser cladded coating 4104 includes a plurality of sections 4104b having greater thickness than the rest of the laser cladded coating 4104 in areas of the expansion system 4100 likely to experience higher wear.

[000394] In an exemplary embodiment, the thickness 4104a ranges between 0.020 and 0.100 inches. In an exemplary embodiment, the laser cladded coating 4104 includes tungsten carbide in a cobalt matrix which is applied to the expansion device 4102 using High Velocity Oxy-Fuel (HVOF). In an exemplary embodiment, the laser cladded coating 4104 may be applied to the expansion device 4102 by applying a finely divided and graded conglomerate of tungsten carbide and finely divided metal such as, for example, nickel or cobalt, with the use of a laser. The conglomerate passes through the path of the laser, which is directed at the outer expansion surface 4102a, and produces a fully metallurgical bond due to the outer expansion surface 4102a melting along with the finely divided metal. The process produces a cladding which has a relatively higher bond strength than conventional powder metallurgy processes such as, for example, flame spray, compaction, D-gun, etc.

[000395] In operation, the expansion system 4100 may be displaced through a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b, in order to radially expand and plastically deform the tubular member. The laser cladded coating 4104 prevents galling of the expansion system 4100 during operation.

[000396] Referring now to Fig. 42a, an alternative embodiment of an expansion system 4200 is substantially identical in design and operation to the expansion system 4100, described above with reference to Fig. 41a, with the provision of diamond coating 4202 on the surface of the laser cladded coating 4104. The diamond coating 4202 and laser cladded coating 4104 include provide a wear resistance and are of a thickness which is sufficient to impart a strength, toughness, and bond strength to the expansion device 4102 and a hardness in order to expand a tubular member which may be, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b, by displacing the expansion system 4200 through the tubular member at a controlled rate. The addition of the diamond coating 4202 decreases the friction coefficient between the expansion system 4200 and the inside surface of a tubular member to be expanded while increasing the resistance of the expansion system 4200 to wear and galling. In an exemplary embodiment, the diamond coating 4202 has a thickness on the order of microns as compared to the thickness 4104a of the laser cladded coating 4104, which may be between 0.020 and 0.100 inches. The diamond coating 4202 may be added to the expansion system 4102 using conventional methods known in the art. In an exemplary embodiment, the expansion device 3400 may be adjustable and/or adaptable in order to expand a tubular member such as, for example, the tubular members 2316, 2600, 2700a, 2700b, and 3406 illustrated in Figs. 21a, 21b, 25a, 25b, 25c, 33a, and 33b.

[000397] In other alternative embodiments, one or more of the embodiments of the present disclosure are implemented using the methods and/or apparatus disclosed in one or more of the following: (1) U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98,

(2) U.S. patent application serial no. 09/510,913, attorney docket no. 25791.7.02, filed on 2/23/2000, which claims priority from provisional application 60/121,702, filed on 2/25/99, (3) U.S. Patent Number 6,823,937, which was filed as U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (4) U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (5) U.S. patent application serial no. 10/169,434, attorney docket no. 25791.10.04, filed on 7/1/02, which claims priority from provisional application 60/183,546, filed on 2/18/00, (6) U.S. patent no. 6,640,903 which was filed as U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, which claims priority from provisional application 60/124,042, filed on 3/11/99, (7) U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (8) U.S. patent number 6,575,240, which was filed as patent application serial no. 09/511,941, attorney docket no. 25791.16.02, filed on 2/24/2000, which claims priority from provisional application 60/121,907, filed on 2/26/99, (9) U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (10) U.S. patent application serial no. 09/981,916, attorney docket no. 25791.18, filed on 10/18/01 as a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (11) U.S. patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (12) U.S. patent application serial no. 10/030,593, attorney docket no. 25791.25.08, filed on 1/8/02, which claims priority from provisional application 60/146,203, filed on 7/29/99, (13) U.S. provisional patent application serial no. 60/143,039, attorney docket no. 25791.26, filed on 7/9/99, (14) U.S. patent application serial no. 10/111,982, attorney docket no. 25791.27.08, filed on 4/30/02, which claims priority from provisional patent application serial no. 60/162,671, attorney docket no. 25791.27, filed on 11/1/1999, (15) U.S. provisional patent application serial no. 60/154,047, attorney docket no. 25791.29, filed on 9/16/1999, (16) U.S. provisional patent application serial no. 60/438,828, attorney docket no. 25791.31, filed on 1/9/03, (17) U.S. patent number 6,564,875, which was filed as application serial no. 09/679,907, attorney docket no. 25791.34.02, on 10/5/00, which claims priority from provisional patent application serial no. 60/159,082, attorney docket no. 25791.34, filed on 10/12/1999, (18) U.S. patent application serial no. 10/089,419, filed on 3/27/02, attorney docket no. 25791.36.03, which claims priority from provisional patent application serial no. 60/159,039, attorney docket no. 25791.36, filed on 10/12/1999, (19) U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (20) U.S. patent application serial no. 10/303,992, filed on 11/22/02, attorney docket no. 25791.38.07, which claims priority from provisional patent application serial no. 60/212,359, attorney docket no. 25791.38, filed on 6/19/2000, (21) U.S. provisional patent application serial no. 60/165,228, attorney docket no. 25791.39, filed on 11/12/1999, (22) U.S. provisional patent application serial no. 60/455,051, attorney docket no. 25791.40, filed on 3/14/03, (23) PCT application US02/2477, filed on 6/26/02, attorney docket no. 25791.44.02, which claims priority from U.S. provisional patent application serial no. 60/303,711, attorney docket no. 25791.44, filed on 7/6/01, (24) U.S. patent application serial no. 10/311,412, filed on 12/12/02, attorney docket no. 25791.45.07, which claims priority from provisional patent application serial no.



60/221,443, attorney docket no. 25791.45, filed on 7/28/2000, (25) U.S. patent application serial no. 10/, filed on 12/18/02, attorney docket no. 25791.46.07, which claims priority from provisional patent application serial no. 60/221,645, attorney docket no. 25791.46, filed on 7/28/2000, (26) U.S. patent application serial no. 10/322,947, filed on 1/22/03, attorney docket no. 25791.47.03, which claims priority from provisional patent application serial no. 60/233,638, attorney docket no. 25791.47, filed on 9/18/2000, (27) U.S. patent application serial no. 10/406,648, filed on 3/31/03, attorney docket no. 25791.48.06, which claims priority from provisional patent application serial no. 60/237,334, attorney docket no. 25791.48, filed on 10/2/2000, (28) PCT application US02/04353, filed on 2/14/02, attorney docket no. 25791.50.02, which claims priority from U.S. provisional patent application serial no. 60/270,007, attorney docket no. 25791.50, filed on 2/20/2001, (29) U.S. patent application serial no. 10/465,835, filed on 6/13/03, attorney docket no. 25791.51.06, which claims priority from provisional patent application serial no. 60/262,434, attorney docket no. 25791.51, filed on 1/17/2001, (30) U.S. patent application serial no. 10/465,831, filed on 6/13/03, attorney docket no. 25791.52.06, which claims priority from U.S. provisional patent application serial no. 60/259,486, attorney docket no. 25791.52, filed on 1/3/2001, (31) U.S. provisional patent application serial no. 60/452,303, filed on 3/5/03, attorney docket no. 25791.53, (32) U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (33) U.S. patent number 6,561,227, which was filed as patent application serial number 09/852,026, filed on 5/9/01, attorney docket no. 25791.56, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (34) U.S. patent application serial number 09/852,027, filed on 5/9/01, attorney docket no. 25791.57, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (35) PCT Application US02/25608, attorney docket no. 25791.58.02, filed on 8/13/02, which claims priority from provisional application 60/318,021, filed on 9/7/01, attorney docket no. 25791.58, (36) PCT Application US02/24399, attorney docket no. 25791.59.02, filed on 8/1/02, which claims priority from U.S. provisional patent application serial no. 60/313,453, attorney docket no. 25791.59, filed on 8/20/2001, (37) PCT Application US02/29856, attorney docket no. 25791.60.02, filed on 9/19/02, which claims priority from U.S. provisional patent application serial no. 60/326,886, attorney docket no. 25791.60, filed on 10/3/2001, (38) PCT Application US02/20256, attorney docket no. 25791.61.02, filed on 6/26/02, which claims priority from U.S. provisional patent application serial no. 60/303,740, attorney docket no. 25791.61, filed on 7/6/2001, (39) U.S. patent application serial no. 09/962,469, filed on 9/25/01, attorney docket no. 25791.62, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (40) U.S. patent application serial no. 09/962,470, filed on 9/25/01, attorney docket no. 25791.63, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (41) U.S. patent application serial no. 09/962,471, filed on 9/25/01, attorney docket no. 25791.64, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from



provisional application 60/124,042, filed on 3/11/99, (42) U.S. patent application serial no. 09/962,467, filed on 9/25/01, attorney docket no. 25791.65, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (43) U.S. patent application serial no. 09/962,468, filed on 9/25/01, attorney docket no. 25791.66, which is a divisional of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (44) PCT application US 02/25727, filed on 8/14/02, attorney docket no. 25791.67.03, which claims priority from U.S. provisional patent application serial no. 60/317,985, attorney docket no. 25791.67, filed on 9/6/2001, and U.S. provisional patent application serial no. 60/318,386, attorney docket no. 25791.67.02, filed on 9/10/2001, (45) PCT application US 02/39425, filed on 12/10/02, attorney docket no. 25791.68.02, which claims priority from U.S. provisional patent application serial no. 60/343,674, attorney docket no. 25791.68, filed on 12/27/2001, (46) U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (47) U.S. utility patent application serial no. 10/516,467, attorney docket no. 25791.70, filed on 12/10/01, which is a continuation application of U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (48) PCT application US 03/00609, filed on 1/9/03, attorney docket no. 25791.71.02, which claims priority from U.S. provisional patent application serial no. 60/357,372, attorney docket no. 25791.71, filed on 2/15/02, (49) U.S. patent application serial no. 10/074,703, attorney docket no. 25791.74, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (50) U.S. patent application serial no. 10/074,244, attorney docket no. 25791.75, filed on 2/12/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (51) U.S. patent application serial no. 10/076,660, attorney docket no. 25791.76, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (52) U.S. patent application serial no. 10/076,661, attorney docket no. 25791.77, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (53) U.S. patent application serial no. 10/076,659, attorney docket no. 25791.78, filed on 2/15/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (54) U.S. patent application serial no. 10/078,928, attorney docket no. 25791.79, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on

2/26/99, (55) U.S. patent application serial no. 10/078,922, attorney docket no. 25791.80, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (56) U.S. patent application serial no. 10/078,921, attorney docket no. 25791.81, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (57) U.S. patent application serial no. 10/261,928, attorney docket no. 25791.82, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (58) U.S. patent application serial no. 10/079,276, attorney docket no. 25791.83, filed on 2/20/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (59) U.S. patent application serial no. 10/262,009, attorney docket no. 25791.84, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (60) U.S. patent application serial no. 10/092,481, attorney docket no. 25791.85, filed on 3/7/02, which is a divisional of U.S. patent number 6,568,471, which was filed as patent application serial no. 09/512,895, attorney docket no. 25791.12.02, filed on 2/24/2000, which claims priority from provisional application 60/121,841, filed on 2/26/99, (61) U.S. patent application serial no. 10/261,926, attorney docket no. 25791.86, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (62) PCT application US 02/36157, filed on 11/12/02, attorney docket no. 25791.87.02, which claims priority from U.S. provisional patent application serial no. 60/338,996, attorney docket no. 25791.87, filed on 11/12/01, (63) PCT application US 02/36267, filed on 11/12/02, attorney docket no. 25791.88.02, which claims priority from U.S. provisional patent application serial no. 60/339,013, attorney docket no. 25791.88, filed on 11/12/01, (64) PCT application US 03/11765, filed on 4/16/03, attorney docket no. 25791.89.02, which claims priority from U.S. provisional patent application serial no. 60/383,917, attorney docket no. 25791.89, filed on 5/29/02, (65) PCT application US 03/15020, filed on 5/12/03, attorney docket no. 25791.90.02, which claims priority from U.S. provisional patent application serial no. 60/391,703, attorney docket no. 25791.90, filed on 6/26/02, (66) PCT application US 02/39418, filed on 12/10/02, attorney docket no. 25791.92.02, which claims priority from U.S. provisional patent application serial no. 60/346,309, attorney docket no. 25791.92, filed on 1/7/02, (67) PCT application US 03/06544, filed on 3/4/03, attorney docket no. 25791.93.02, which claims priority from U.S. provisional patent application serial no. 60/372,048, attorney docket no. 25791.93, filed on 4/12/02, (68) U.S. patent application serial no. 10/331,718, attorney docket no. 25791.94, filed on 12/30/02, which is a divisional U.S. patent application serial no. 09/679,906, filed on 10/5/00, attorney docket no. 25791.37.02, which claims priority from provisional patent application serial no. 60/159,033, attorney docket no. 25791.37, filed on 10/12/1999, (69) PCT application US 03/04837, filed on 2/29/03, attorney docket no. 25791.95.02, which claims priority from U.S. provisional patent application serial no. 60/363,829, attorney docket no. 25791.95, filed on 3/13/02, (70) U.S. patent application serial no. 10/261,927, attorney docket no. 25791.97, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on

6/7/99, (71) U.S. patent application serial no. 10/262,008, attorney docket no. 25791.98, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (72) U.S. patent application serial no. 10/261,925, attorney docket no. 25791.99, filed on 10/1/02, which is a divisional of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (73) U.S. patent application serial no. 10/199,524, attorney docket no. 25791.100, filed on 7/19/02, which is a continuation of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (74) PCT application US 03/10144, filed on 3/28/03, attorney docket no. 25791.101.02, which claims priority from U.S. provisional patent application serial no. 60/372,632, attorney docket no. 25791.101, filed on 4/15/02, (75) U.S. provisional patent application serial no. 60/412,542, attorney docket no. 25791.102, filed on 9/20/02, (76) PCT application US 03/14153, filed on 5/6/03, attorney docket no. 25791.104.02, which claims priority from U.S. provisional patent application serial no. 60/380,147, attorney docket no. 25791.104, filed on 5/6/02, (77) PCT application US 03/19993, filed on 6/24/03, attorney docket no. 25791.106.02, which claims priority from U.S. provisional patent application serial no. 60/397,284, attorney docket no. 25791.106, filed on 7/19/02, (78) PCT application US 03/13787, filed on 5/5/03, attorney docket no. 25791.107.02, which claims priority from U.S. provisional patent application serial no. 60/387,486, attorney docket no. 25791.107, filed on 6/10/02, (79) PCT application US 03/18530, filed on 6/11/03, attorney docket no. 25791.108.02, which claims priority from U.S. provisional patent application serial no. 60/387,961, attorney docket no. 25791.108, filed on 6/12/02, (80) PCT application US 03/20694, filed on 7/1/03, attorney docket no. 25791.110.02, which claims priority from U.S. provisional patent application serial no. 60/398,061, attorney docket no. 25791.110, filed on 7/24/02, (81) PCT application US 03/20870, filed on 7/2/03, attorney docket no. 25791.111.02, which claims priority from U.S. provisional patent application serial no. 60/399,240, attorney docket no. 25791.111, filed on 7/29/02, (82) U.S. provisional patent application serial no. 60/412,487, attorney docket no. 25791.112, filed on 9/20/02, (83) U.S. provisional patent application serial no. 60/412,488, attorney docket no. 25791.114, filed on 9/20/02, (84) U.S. patent application serial no. 10/280,356, attorney docket no. 25791.115, filed on 10/25/02, which is a continuation of U.S. patent number 6,470,966, which was filed as patent application serial number 09/850,093, filed on 5/7/01, attorney docket no. 25791.55, as a divisional application of U.S. Patent Number 6,497,289, which was filed as U.S. Patent Application serial no. 09/454,139, attorney docket no. 25791.03.02, filed on 12/3/1999, which claims priority from provisional application 60/111,293, filed on 12/7/98, (85) U.S. provisional patent application serial no. 60/412,177, attorney docket no. 25791.117, filed on 9/20/02, (86) U.S. provisional patent application serial no. 60/412,653, attorney docket no. 25791.118, filed on 9/20/02, (87) U.S. provisional patent application serial no. 60/405,610, attorney docket no. 25791.119, filed on 8/23/02, (88) U.S. provisional patent application serial no. 60/405,394, attorney docket no. 25791.120, filed on 8/23/02, (89) U.S. provisional patent application serial no. 60/412,544, attorney docket no. 25791.121, filed on 9/20/02, (90) PCT application US 03/24779, filed on 8/8/03, attorney docket no. 25791.125.02, which claims priority from U.S. provisional patent application serial no. 60/407,442, attorney docket no. 25791.125, filed on 8/30/02, (91) U.S. provisional patent application serial no. 60/423,363, attorney docket no. 25791.126, filed on 12/10/02, (92) U.S. provisional patent application serial no. 60/412,196, attorney docket no. 25791.127, filed on 9/20/02, (93) U.S. provisional patent application serial no. 60/412,187, attorney docket no. 25791.128, filed on 9/20/02, (94) U.S.



provisional patent application serial no. 60/412,371, attorney docket no. 25791.129, filed on 9/20/02, (95) U.S. patent application serial no. 10/382,325, attorney docket no. 25791.145, filed on 3/5/03, which is a continuation of U.S. patent number 6,557,640, which was filed as patent application serial no. 09/588,946, attorney docket no. 25791.17.02, filed on 6/7/2000, which claims priority from provisional application 60/137,998, filed on 6/7/99, (96) U.S. patent application serial no. 10/624,842, attorney docket no. 25791.151, filed on 7/22/03, which is a divisional of U.S. patent application serial no. 09/502,350, attorney docket no. 25791.8.02, filed on 2/10/2000, which claims priority from provisional application 60/119,611, filed on 2/11/99, (97) U.S. provisional patent application serial no. 60/431,184, attorney docket no. 25791.157, filed on 12/5/02, (98) U.S. provisional patent application serial no. 60/448,526, attorney docket no. 25791.185, filed on 2/18/03, (99) U.S. provisional patent application serial no. 60/461,539, attorney docket no. 25791.186, filed on 4/9/03, (100) U.S. provisional patent application serial no. 60/462,750, attorney docket no. 25791.193, filed on 4/14/03, (101) U.S. provisional patent application serial no. 60/436,106, attorney docket no. 25791.200, filed on 12/23/02, (102) U.S. provisional patent application serial no. 60/442,942, attorney docket no. 25791.213, filed on 1/27/03, (103) U.S. provisional patent application serial no. 60/442,938, attorney docket no. 25791.225, filed on 1/27/03, (104) U.S. provisional patent application serial no. 60/418,687, attorney docket no. 25791.228, filed on 4/18/03, (105) U.S. provisional patent application serial no. 60/454,896, attorney docket no. 25791.236, filed on 3/14/03, (106) U.S. provisional patent application serial no. 60/450,504, attorney docket no. 25791.238, filed on 2/26/03, (107) U.S. provisional patent application serial no. 60/451,152, attorney docket no. 25791.239, filed on 3/9/03, (108) U.S. provisional patent application serial no. 60/455,124, attorney docket no. 25791.241, filed on 3/17/03, (109) U.S. provisional patent application serial no. 60/453,678, attorney docket no. 25791.253, filed on 3/11/03, (110) U.S. patent application serial no. 10/421,682, attorney docket no. 25791.256, filed on 4/23/03, which is a continuation of U.S. patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99, (111) U.S. provisional patent application serial no. 60/457,965, attorney docket no. 25791.260, filed on 3/27/03, (112) U.S. provisional patent application serial no. 60/455,718, attorney docket no. 25791.262, filed on 3/18/03, (113) U.S. patent number 6,550,821, which was filed as patent application serial no. 09/811,734, filed on 3/19/01, (114) U.S. patent application serial no. 10/436,467, attorney docket no. 25791.268, filed on 5/12/03, which is a continuation of U.S. patent number 6,604,763, which was filed as application serial no. 09/559,122, attorney docket no. 25791.23.02, filed on 4/26/2000, which claims priority from provisional application 60/131,106, filed on 4/26/99, (115) U.S. provisional patent application serial no. 60/459,776, attorney docket no. 25791.270, filed on 4/2/03, (116) U.S. provisional patent application serial no. 60/461,094, attorney docket no. 25791.272, filed on 4/8/03, (117) U.S. provisional patent application serial no. 60/461,038, attorney docket no. 25791.273, filed on 4/7/03, (118) U.S. provisional patent application serial no. 60/463,586, attorney docket no. 25791.277, filed on 4/17/03, (119) U.S. provisional patent application serial no. 60/472,240, attorney docket no. 25791.286, filed on 5/20/03, (120) U.S. patent application serial no. 10/619,285, attorney docket no. 25791.292, filed on 7/14/03, which is a continuation-in-part of U.S. utility patent application serial no. 09/969,922, attorney docket no. 25791.69, filed on 10/3/2001, (now U.S. Patent 6,634,431 which issued 10/21/2003), which is a continuation-in-part application of U.S. patent no. 6,328,113, which was filed as U.S. Patent Application serial number 09/440,338, attorney docket number 25791.9.02, filed on 11/15/99, which claims priority from provisional application 60/108,558, filed on 11/16/98, (121) U.S. utility patent application serial no. 10/418,688, attorney docket no. 25791.257, which was filed on 4/18/03, as a division of U.S. utility patent application serial no. 09/523,468, attorney docket no. 25791.11.02, filed



on 3/10/2000, (now U.S. Patent 6,640,903 which issued 11/4/2003), which claims priority from provisional application 60/124,042, filed on 3/11/99; (122) PCT patent application serial no. PCT/US2004/06246, attorney docket no. 25791.238.02, filed on 2/26/2004; (123) PCT patent application serial number PCT/US2004/08170, attorney docket number 25791.40.02, filed on 3/15/04; (124) PCT patent application serial number PCT/US2004/08171, attorney docket number 25791.236.02, filed on 3/15/04; (125) PCT patent application serial number PCT/US2004/08073, attorney docket number 25791.262.02, filed on 3/18/04; (126) PCT patent application serial number PCT/US2004/07711, attorney docket number 25791.253.02, filed on 3/11/2004; (127) PCT patent application serial number PCT/US2004/029025, attorney docket number 25791.260.02, filed on 3/26/2004; (128) PCT patent application serial number PCT/US2004/010317, attorney docket number 25791.270.02, filed on 4/2/2004; (129) PCT patent application serial number PCT/US2004/010712, attorney docket number 25791.272.02, filed on 4/6/2004; (130) PCT patent application serial number PCT/US2004/010762, attorney docket number 25791.273.02, filed on 4/6/2004; (131) PCT patent application serial number PCT/US2004/011973, attorney docket number 25791.277.02, filed on 4/15/2004; (132) U.S. provisional patent application serial number 60/495056, attorney docket number 25791.301, filed on 8/14/2003; (133) U.S. provisional patent application serial number 60/600679, attorney docket number 25791.194, filed on 8/11/2004; (134) PCT patent application serial number PCT/US2005/027318, attorney docket number 25791.329.02, filed on 7/29/2005; (135) PCT patent application serial number PCT/US2005/028936, attorney docket number 25791.338.02, filed on 8/12/2005; (136) PCT patent application serial number PCT/US2005/028669, attorney docket number 25791.194.02, filed on 8/11/2005; (137) PCT patent application serial number PCT/US2005/028453, attorney docket number 25791.371, filed on 8/11/2005; (138) PCT patent application serial number PCT/US2005/028641, attorney docket number 25791.372, filed on 8/11/2005; (139) PCT patent application serial number PCT/US2005/028819, attorney docket number 25791.373, filed on 8/11/2005; (140) PCT patent application serial number PCT/US2005/028446, attorney docket number 25791.374, filed on 8/11/2005; (141) PCT patent application serial number PCT/US2005/028642, attorney docket number 25791.375, filed on 8/11/2005; (142) PCT patent application serial number PCT/US2005/028451, attorney docket number 25791.376, filed on 8/11/2005, and (143). PCT patent application serial number PCT/US2005/028473, attorney docket number 25791.377, filed on 8/11/2005, (144) U.S. utility patent application serial number 10/546082, attorney docket number 25791.378, filed on 8/16/2005, (145) U.S. utility patent application serial number 10/546076, attorney docket number 25791.379, filed on 8/16/2005, (146) U.S. utility patent application serial number 10/545936, attorney docket number 25791.380, filed on 8/16/2005, (147) U.S. utility patent application serial number 10/546079, attorney docket number 25791.381, filed on 8/16/2005 (148) U.S. utility patent application serial number 10/545941, attorney docket number 25791.382, filed on 8/16/2005, (149) U.S. utility patent application serial number 546078, attorney docket number 25791.383, filed on 8/16/2005, filed on 8/11/2005., (150) U.S. utility patent application serial number 10/545941, attorney docket number 25791.185.05, filed on 8/16/2005, (151) U.S. utility patent application serial number 11/249967, attorney docket number 25791.384, filed on 10/13/2005, (152) U.S. provisional patent application serial number 60/734302, attorney docket number 25791.24, filed on 11/7/2005, (153) U.S. provisional patent application serial number 60/725181, attorney docket number 25791.184, filed on 10/11/2005, (154) PCT patent application serial number PCT/US2005/023391, attorney docket number 25791.299.02 filed 6/29/2005 which claims priority from U.S. provisional patent application serial number 60/585370, attorney docket number 25791.299, filed on 7/2/2004, (155) U.S. provisional patent application serial number 60/721579, attorney docket number 25791.327, filed on 9/28/2005, (156) U.S. provisional patent application serial number 60/717391, attorney docket number 25791.214,

filed on 9/15/2005, (157) U.S. provisional patent application serial number 60/702935, attorney docket number 25791.133, filed on 7/27/2005, (158) U.S. provisional patent application serial number 60/663913, attorney docket number 25791.32, filed on 3/21/2005, (159) U.S. provisional patent application serial number 60/652564, attorney docket number 25791.348, filed on 2/14/2005, (160) U.S. provisional patent application serial number 60/645840, attorney docket number 25791.324, filed on 1/21/2005, (161) PCT patent application serial number PCT/US2005/\_\_\_\_\_, attorney docket number 25791.326.02, filed on 11/29/2005 which claims priority from U.S. provisional patent application serial number 60/631703, attorney docket number 25791.326, filed on 11/30/2004, (162) U.S. provisional patent application serial number \_\_\_\_\_, attorney docket number 25791.339, filed on 12/22/2005, (163) U.S. National Stage application serial no. 10/548934, attorney docket no. 25791.253.05, filed on 9/12/2005; (164) U.S. National Stage application serial no. 10/549410, attorney docket no. 25791.262.05, filed on 9/13/2005; (165) U.S. Provisional Patent Application No. 60/717391, attorney docket no. 25791.214 filed on 9/15/2005; (166) U.S. National Stage application serial no. 10/550906, attorney docket no. 25791.260.06, filed on 9/27/2005; (167) U.S. National Stage application serial no. 10/551880, attorney docket no. 25791.270.06, filed on 9/30/2005; (168) U.S. National Stage application serial no. 10/552253, attorney docket no. 25791.273.06, filed on 10/4/2005; (169) U.S. National Stage application serial no. 10/552790, attorney docket no. 25791.272.06, filed on 10/11/2005; (170) U.S. Provisional Patent Application No. 60/725181, attorney docket no. 25791.184 filed on 10/11/2005; (171) U.S. National Stage application serial no. 10/553094, attorney docket no. 25791.193.03, filed on 10/13/2005; (172) U.S. National Stage application serial no. 10/553566, attorney docket no. 25791.277.06, filed on 10/17/05; (173) PCT Patent Application No. PCT/US2006/\_\_\_\_\_, attorney docket no. 25791.324.02 filed on 1/20/06, and (174) PCT Patent Application No. PCT/US2006/\_\_\_\_\_, attorney docket no. 25791.348.02 filed on 2/9/06; (175) U.S. Utility Patent application serial no. \_\_\_\_\_, attorney docket no. 25791.386, filed on 2/17/06, (176) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.301.06, filed on \_\_\_\_\_, (177) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.137.04, filed on \_\_\_\_\_, (178) U.S. National Stage application serial no. \_\_\_\_\_, attorney docket no. 25791.215.06, filed on \_\_\_\_\_.

[000398] It is understood that variations may be made in the foregoing without departing from the scope of the invention. For example, the teachings of the present illustrative embodiments may be used to provide a wellbore casing, a pipeline, or a structural support. Furthermore, one or more of tubular members such as, for example, the tubular members 2316, 2600, or 2700a and 2700b, described above with reference to Figs. 21a, 25a, and 25b, may be slotted, perforated, or otherwise include one or more radial passages.

[000399] In several exemplary embodiment, the apparatus 200, 300, 400, and 800, the assemblies 500, 600, 700, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, and 2200, and the devices 2314, 2414, 2500, 2900, 3000, 3100, 3200, 3300, 3400, 3500, 3600, 3700, 3802, 3900, 4002, and 4102 may provide an adjustable and/or adaptable system for expanding a tubular member.

[000400] An expansion apparatus has been described that includes an expansion device operable to expand an expandable tubular member including an expansion device segment for defining an outer surface of the expansion device, and a cam movably coupled to the expansion device segment, wherein the cam is operable to be rotated from a first position to define the outer surface in a first small diameter configuration, and a second position to define the outer surface in a second large diameter configuration. In an exemplary embodiment, the expansion device includes a plurality of expansion device segments. In an exemplary embodiment, the cam is movably coupled to the plurality of expansion device segments. In an exemplary embodiment, the expansion device includes

a plurality of cams movingly coupled to the plurality of expansion device segments. In an exemplary embodiment, the plurality of expansion device segments and the plurality of cams include a first cam movingly coupled to a first plurality of expansion device segments and a second cam movingly coupled to a second plurality of expansion device segments, whereby the first cam and first plurality of expansion device segments are offset along a length of the expansion device from the second cam and second plurality of expansion device segments. In an exemplary embodiment, the expansion device segment is pivotally coupled to a support structure on the expansion device. In an exemplary embodiment, the plurality of expansion device segments are coupled to a support structure which is operable to allow the plurality of expansion device segments to translate laterally relative to each other upon operation of the cam. In an exemplary embodiment, each of the plurality of expansion device segments are slidingly coupled to adjacent expansion device segments. In an exemplary embodiment, the expansion device segment includes an expansion device roller. In an exemplary embodiment, the plurality of expansion device segments includes a first plurality of expansion device segments which are interlaced with a second plurality of expansion device segments. In an exemplary embodiment, an expansion system is coupled to the expansion device for adaptively expanding the expansion device which includes a controller coupled to the expansion device, a sensor coupled to the controller, and a user interface coupled to the controller. In an exemplary embodiment, a driving mechanism is coupled to the cam. In an exemplary embodiment, a motor is coupled to the driving mechanism. In an exemplary embodiment, an expandable tubular member is included which is operable to be expanded by the expansion device, whereby the expansion device is positioned within the expandable tubular member.

[000401] An expansion apparatus has been described which includes an expansion device operable to expand an expandable tubular member including a mandrel which is operable to be connected to a string, a plurality of expansion device segments movingly mounted to the mandrel and defining an outer surface of the expansion device, a first collet mounted on the mandrel, positioned above the plurality of expansion device segments, and operable to engage the plurality of expansion device segments, and a second collet mounted on the mandrel, positioned below the plurality of expansion portions, and operable to engage the plurality of expansion device segments, whereby the outer surface is configured in a first small diameter configuration in response to the first collet and the second collet being positioned in a first position, and the outer surface is configured in a second large diameter configuration in response to the first collet and the second collet engaging the plurality of expansion device segments and being positioned in a second position. In an exemplary embodiment, a driving mechanism is included for moving the collets between the first position and the second position. In an exemplary embodiment, the first collet and the second collet move along the mandrel between the first position and the second position. In an exemplary embodiment, the plurality of expansion device segments are coupled to a support structure on the mandrel which is operable to allow the expansion device segments to translate laterally relative to each other upon operation of the first collet and the second collet. In an exemplary embodiment, an expandable tubular member is included, whereby the expansion device is positioned within the expandable tubular member.

[000402] An expansion apparatus has been described which includes an expansion device operable to expand an expandable tubular member including a support member, a first piston actuation structure mounted on the support member, a second piston actuation structure mounted on the support member, a first axle mounted between the first piston actuation structure and the second piston actuation structure, and an expansion device segment mounted on the first axle and defining an outer surface of the expansion device, whereby the first piston actuation structure and the second piston actuation structure are operable to be actuated to configure the outer surface in one of either a first small diameter configuration and a second large diameter configuration. In an exemplary embodiment, a first fluid



passage is included between the first piston actuation structure and an interior of the support member, and a second fluid passage is included between the second piston actuation structure and the interior of the support member. In an exemplary embodiment, a second axle is mounted between the first piston actuation structure and the second piston actuation structure, and an expansion device segment is mounted on the second axle. In an exemplary embodiment, the expansion device segment includes an expansion device roller. In an exemplary embodiment, an expandable tubular member is included, whereby the expansion device is positioned within the expandable tubular member.

[000403] An expansion apparatus has been described which includes an expansion device operable to expand an expandable tubular member, the expansion device including a bladder comprising an interior of the expansion device, and a device outer skin exterior to the bladder, whereby the bladder is operable to expand the device outer skin from a first small diameter configuration to a second large diameter configuration. In an exemplary embodiment, a plurality of inserts are included exterior to the device outer skin. In an exemplary embodiment, a support member is included, wherein the expansion device is mounted on the support member. In an exemplary embodiment, a fluid passage is included between an interior of the support member and the bladder. In an exemplary embodiment, the device outer skin includes a metal. In an exemplary embodiment, an expandable tubular member is included, whereby the expansion device is positioned within the expandable tubular member.

[000404] An expansion apparatus has been described which includes an expansion device operable to expand an expandable tubular member, the expansion device including a plurality of small sections, and a plurality of large sections, whereby each small section is positioned between two adjacent large sections, each large section is positioned between two adjacent small sections, and the plurality of small sections and the plurality of large sections are expandable from a first small diameter configuration to a second large diameter configuration. In an exemplary embodiment, a support mandrel is included to hold the plurality of small sections and the plurality of large sections in the second large diameter configuration. In an exemplary embodiment, a retaining sleeve is included to hold the plurality of small sections and the plurality of large sections in the first small diameter configuration. In an exemplary embodiment, a section retainer is included, whereby the plurality of small sections and the plurality of large sections are pivotally mounted to the section retainer. In an exemplary embodiment, a section retainer is included, whereby the plurality of small sections and the plurality of large sections are cantilevered off of the section retainer. In an exemplary embodiment, an expandable tubular member is included, whereby the expansion device is positioned within the expandable tubular member.

[000405] An expansion apparatus has been described which includes an expansion device operable to expand an expandable tubular member, the expansion device including a support structure, expansion means for defining an outer surface of the expansion device which is coupled to the support structure, and control means for positioning the expansion means between a first small diameter configuration and a second large diameter configuration.

[000406] A method for expanding a tubular member has been described that includes providing an expansion device including a plurality of expansion device segments which define an outer surface of the expansion device, movingly coupling a cam to the plurality of expansion device segments, configuring the expansion device segments in a first small diameter configuration by rotating the cam, positioning the expansion device in an expandable tubular member, configuring the expansion device segments in a second large diameter configuration by rotating the cam, and expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

[000407] A method for expanding a tubular member has been described that includes providing an expansion



device including a plurality of expansion device segments which define an outer surface of the expansion device, movingly coupling a plurality of collets to the plurality of expansion device segments, configuring the expansion device segments in a first small diameter configuration by moving the plurality of collets, positioning the expansion device in an expandable tubular member, configuring the expansion device segments in a second large diameter configuration by moving the plurality of collets, and expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

[000408] A method for expanding a tubular member has been described that includes providing an expansion device including a plurality of expansion device segments which define an outer surface of the expansion device, coupling the plurality of expansion device segments to a plurality of piston type actuators, configuring the expansion device segments in a first small diameter configuration by actuating the piston type actuators, positioning the expansion device in an expandable tubular member, configuring the expansion device segments in a second large diameter configuration by actuating the piston type actuators, and expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

[000409] A method for expanding a tubular member has been described that includes providing an expansion device including a bladder and an outer device skin which defines an outer surface of the expansion device, configuring the expansion device segments in a first small diameter configuration by removing a fluid from the bladder, positioning the expansion device in an expandable tubular member, configuring the expansion device segments in a second large diameter configuration by adding fluid to the bladder, and expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

[000410] A method for expanding a tubular member has been described that includes providing an expansion device including a plurality of small sections and a plurality of large sections, whereby each small section is positioned between two adjacent large sections, each large section is positioned between two adjacent small sections, and the plurality of small sections and the plurality of large sections are expandable from a first small diameter configuration to a second large diameter configuration, configuring the expansion device segments in the first small diameter configuration by holding the small sections and the large sections in the first small diameter configuration with the use of a retaining sleeve, positioning the expansion device in an expandable tubular member, configuring the expansion device segments in a second large diameter configuration by engaging the small sections and the large sections with a support mandrel, and expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

[000411] An apparatus has been described which includes an expandable tubular member, and an expansion sleeve coupled to the expandable tubular member which is operable to decouple from the expandable tubular member and couple to an expansion device in order to increase an outside diameter of the expansion device. In an exemplary embodiment, a plurality of shear pins are included for coupling the expansion sleeve to the expandable tubular member. In an exemplary embodiment, an expansion device is positioned in the expandable tubular member and operable to couple to the expansion sleeve to expand from a first small diameter configuration to a second large diameter configuration.

[000412] An expansion apparatus has been described that includes an expandable tubular member, and expansion means coupled to the expandable tubular member for increasing the outside diameter of an expansion device.

[000413] A method for expanding an expandable tubular member has been described that includes providing an expandable tubular member, coupling an expansion sleeve to the expandable tubular member, positioning an

expansion device in the expandable tubular member, displacing the expansion device through the expandable tubular member, increasing the outside diameter of the expansion device by engaging the expansion device with the expansion sleeve and coupling the expansion sleeve to the expansion device while decoupling the expansion sleeve from the expandable tubular member, and expanding the expandable tubular member by displacing the expansion device with the expansion sleeve through the expandable tubular member.

[000414] An expansion apparatus has been described that includes an expansion device comprising a working outer surface, and a laser cladded coating on the working outer surface. In an exemplary embodiment, the laser cladded coating has a thickness of approximately 0.020 inches to 0.100 inches. In an exemplary embodiment, the laser cladded coating includes at least one section having a substantially greater thickness than the rest of the laser cladded coating positioned on an area of the expansion device likely to experience greater wear. In an exemplary embodiment, the laser cladded coating increases the resistance of the expansion device from galling. In an exemplary embodiment, a diamond coating layer is included on the laser cladded coating. In an exemplary embodiment, the diamond coating layer decreases the coefficient of the expansion device.

[000415] A method for expanding an expandable tubular member has been described that includes providing an expandable tubular member, providing an expansion device including an outer expansion surface, coating the outer expansion surface with a layer of material by laser-cladding, positioning the expansion device in the expandable tubular member, and expanding the expandable tubular member by displacing the expansion device through the expandable tubular member. In an exemplary embodiment, the method further includes coating the layer of material with a diamond coating. In an exemplary embodiment, the method further includes reducing the coefficient of friction between the expandable tubular member and the expansion device by coating the layer of material with a diamond coating.

[000416] The teachings of the present illustrate embodiments may, for example, be applied to well construction and repair, pipeline construction and repair, and/or building construction and repair.

[000417] Although illustrative embodiments of the invention have been shown and described, a wide range of modification, changes and substitution is contemplated in the foregoing disclosure. In some instances, some features of the present invention may be employed without a corresponding use of the other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

## Claims

What is claimed is:

1. An expansion apparatus, comprising:  
an expansion device operable to expand an expandable tubular member comprising:  
an expansion device segment for defining an outer surface of the expansion device; and  
a cam movingly coupled to the expansion device segment, wherein the cam is operable to be rotated from a first position to define the outer surface in a first small diameter configuration, and a second position to define the outer surface in a second large diameter configuration.
2. The apparatus of claim 1, wherein the expansion device includes a plurality of expansion device segments.
3. The apparatus of claim 2, wherein the cam is movingly coupled to the plurality of expansion device segments.
4. The apparatus of claim 2, wherein the expansion device includes a plurality of cams movingly coupled to the plurality of expansion device segments.
5. The apparatus of claim 4, wherein the plurality of expansion device segments and the plurality of cams comprise a first cam movingly coupled to a first plurality of expansion device segments and a second cam movingly coupled to a second plurality of expansion device segments, whereby the first cam and first plurality of expansion device segments are offset along a length of the expansion device from the second cam and second plurality of expansion device segments.
6. The apparatus of claim 1, wherein the expansion device segment is pivotally coupled to a support structure on the expansion device.
7. The apparatus of claim 2, wherein the plurality of expansion device segments are coupled to a support structure which is operable to allow the plurality of expansion device segments to translate laterally relative to each other upon operation of the cam.
8. The apparatus of claim 2, wherein each of the plurality of expansion device segments are slidably coupled to adjacent expansion device segments.
9. The apparatus of claim 1, wherein the expansion device segment includes an expansion device roller.
10. The apparatus of claim 2, wherein the plurality of expansion device segments includes a first plurality of expansion device segments which are interlaced with a second plurality of expansion device segments.
11. The apparatus of claim 1, further comprising:  
an expansion system coupled to the expansion device for adaptively expanding the expansion device comprising:  
a controller coupled to the expansion device;  
a sensor coupled to the controller; and  
a user interface coupled to the controller.
12. The apparatus of claim 1, further comprising:  
a driving mechanism coupled to the cam.
13. The apparatus of claim 12, further comprising:  
a motor coupled to the driving mechanism.
14. The apparatus of claim 12, further comprising:  
an expandable tubular member operable to be expanded by the expansion device,

whereby the expansion device is positioned within the expandable tubular member.

15. An expansion apparatus, comprising:

- an expansion device operable to expand an expandable tubular member comprising:
- a mandrel which is operable to be connected to a string;
- a plurality of expansion device segments movingly mounted to the mandrel and defining an outer surface of the expansion device;
- a first collet mounted on the mandrel, positioned above the plurality of expansion device segments, and operable to engage the plurality of expansion device segments; and
- a second collet mounted on the mandrel, positioned below the plurality of expansion portions, and operable to engage the plurality of expansion device segments, whereby the outer surface is configured in a first small diameter configuration in response to the first collet and the second collet being positioned in a first position, and the outer surface is configured in a second large diameter configuration in response to the first collet and the second collet engaging the plurality of expansion device segments and being positioned in a second position.

16. The apparatus of claim 15, further comprising:

- a driving mechanism for moving the collets between the first position and the second position.

17. The apparatus of claim 15, wherein the first collet and the second collet move along the mandrel between the first position and the second position.

18. The apparatus of claim 15, wherein the plurality of expansion device segments are coupled to a support structure on the mandrel which is operable to allow the expansion device segments to translate laterally relative to each other upon operation of the first collet and the second collet.

19. The apparatus of claim 15, further comprising:

- an expandable tubular member, whereby the expansion device is positioned within the expandable tubular member.

20. An expansion apparatus, comprising:

- an expansion device operable to expand an expandable tubular member comprising:
- a support member;
- a first piston actuation structure mounted on the support member;
- a second piston actuation structure mounted on the support member;
- a first axle mounted between the first piston actuation structure and the second piston actuation structure; and
- an expansion device segment mounted on the first axle and defining an outer surface of the expansion device, whereby the first piston actuation structure and the second piston actuation structure are operable to be actuated to configure the outer surface in one of either a first small diameter configuration and a second large diameter configuration.

21. The apparatus of claim 20, further comprising:

- a first fluid passage between the first piston actuation structure and an interior of the support member, and a second fluid passage between the second piston actuation structure and the interior of the support member.

22. The apparatus of claim 20, further comprising:



- a second axle mounted between the first piston actuation structure and the second piston actuation structure, and an expansion device segment mounted on the second axle.
23. The apparatus of claim 20, wherein the expansion device segment includes an expansion device roller.
24. The apparatus of claim 20, further comprising:  
an expandable tubular member, whereby the expansion device is positioned within the expandable tubular member.
25. An expansion apparatus, comprising:  
an expansion device operable to expand an expandable tubular member, the expansion device comprising:  
a bladder comprising an interior of the expansion device; and  
a device outer skin exterior to the bladder, whereby the bladder is operable to expand the device outer skin from a first small diameter configuration to a second large diameter configuration.
26. The apparatus of claim 25, further comprising:  
a plurality of inserts exterior to the device outer skin.
27. The apparatus of claim 25, further comprising:  
a support member, wherein the expansion device is mounted on the support member.
28. The apparatus of claim 27, further comprising:  
a fluid passage between an interior of the support member and the bladder.
29. The apparatus of claim 25, wherein the device outer skin includes a metal.
30. The apparatus of claim 25, further comprising:  
an expandable tubular member, whereby the expansion device is positioned within the expandable tubular member.
31. An expansion apparatus, comprising:  
an expansion device operable to expand an expandable tubular member, the expansion device comprising:  
a plurality of small sections; and  
a plurality of large sections, whereby each small section is positioned between two adjacent large sections, each large section is positioned between two adjacent small sections, and the plurality of small sections and the plurality of large sections are expandable from a first small diameter configuration to a second large diameter configuration.
32. The apparatus of claim 31, further comprising:  
a support mandrel to hold the plurality of small sections and the plurality of large sections in the second large diameter configuration.
33. The apparatus of claim 31, further comprising:  
a retaining sleeve to hold the plurality of small sections and the plurality of large sections in the first small diameter configuration.
34. The apparatus of claim 31, further comprising:  
a section retainer, whereby the plurality of small sections and the plurality of large sections are pivotally mounted to the section retainer.
35. The apparatus of claim 31, further comprising:

a section retainer, whereby the plurality of small sections and the plurality of large sections are cantilevered off of the section retainer.

36. The apparatus of claim 31, further comprising:

an expandable tubular member, whereby the expansion device is positioned within the expandable tubular member.

38. A method for expanding a tubular member, comprising:

providing an expansion device including a plurality of expansion device segments which define an outer surface of the expansion device;

movingly coupling a cam to the plurality of expansion device segments;

configuring the expansion device segments in a first small diameter configuration by rotating the cam;

positioning the expansion device in an expandable tubular member;

configuring the expansion device segments in a second large diameter configuration by rotating the cam; and

expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

39. A method for expanding a tubular member, comprising:

providing an expansion device including a plurality of expansion device segments which define an outer surface of the expansion device;

movingly coupling a plurality of collets to the plurality of expansion device segments;

configuring the expansion device segments in a first small diameter configuration by moving the plurality of collets;

positioning the expansion device in an expandable tubular member;

configuring the expansion device segments in a second large diameter configuration by moving the plurality of collets; and

expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

40. A method for expanding a tubular member, comprising:

providing an expansion device including a plurality of expansion device segments which define an outer surface of the expansion device;

coupling the plurality of expansion device segments to a plurality of piston type actuators;

configuring the expansion device segments in a first small diameter configuration by actuating the piston type actuators;

positioning the expansion device in an expandable tubular member;

configuring the expansion device segments in a second large diameter configuration by actuating the piston type actuators; and

expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

41. A method for expanding a tubular member, comprising:

providing an expansion device including a bladder and an outer device skin which

defines an outer surface of the expansion device;

configuring the expansion device segments in a first small diameter configuration by removing a fluid from the bladder;

positioning the expansion device in an expandable tubular member;

configuring the expansion device segments in a second large diameter configuration by adding fluid to the bladder; and

expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

42. A method for expanding a tubular member, comprising:

providing an expansion device including a plurality of small sections and a plurality of large sections, whereby each small section is positioned between two adjacent large sections, each large section is positioned between two adjacent small sections, and the plurality of small sections and the plurality of large sections are expandable from a first small diameter configuration to a second large diameter configuration;

configuring the expansion device segments in the first small diameter configuration by holding the small sections and the large sections in the first small diameter configuration with the use of a retaining sleeve;

positioning the expansion device in an expandable tubular member;

configuring the expansion device segments in a second large diameter configuration by engaging the small sections and the large sections with a support mandrel; and

expanding the expandable tubular member by displacing the expansion device through the expandable tubular member.

43. An apparatus, comprising:

an expandable tubular member; and

an expansion sleeve coupled to the expandable tubular member which is operable to decouple from the expandable tubular member and couple to an expansion device in order to increase an outside diameter of the expansion device.

44. The apparatus of claim 43, further comprising:

a plurality of shear pins coupling the expansion sleeve to the expandable tubular member.

45. The apparatus of claim 43, further comprising:

an expansion device positioned in the expandable tubular member and operable to couple to the expansion sleeve to expand from a first small diameter configuration to a second large diameter configuration.

47. A method for expanding an expandable tubular member, comprising:

providing an expandable tubular member;

coupling an expansion sleeve to the expandable tubular member;

positioning an expansion device in the expandable tubular member;

displacing the expansion device through the expandable tubular member;

increasing the outside diameter of the expansion device by engaging the expansion device with the expansion sleeve and coupling the expansion sleeve to the expansion device while

decoupling the expansion sleeve from the expandable tubular member; and

expanding the expandable tubular member by displacing the expansion device with the expansion sleeve through the expandable tubular member.

48. An expansion apparatus, comprising:

an expansion device comprising a working outer surface; and  
a laser cladded coating on the working outer surface.

49. The apparatus of claim 48, wherein the laser cladded coating comprises a thickness of approximately 0.020 inches to 0.100 inches.

50. The apparatus of claim 48, wherein the laser cladded coating comprises at least one section having a substantially greater thickness than the rest of the laser cladded coating positioned on an area of the expansion device likely to experience greater wear.

51. The apparatus of claim 48, wherein the laser cladded coating increases the resistance of the expansion device from galling.

52. The apparatus of claim 48, further comprising:

a diamond coating layer on the laser cladded coating.

53. The apparatus of claim 52, wherein the diamond coating layer decreases the coefficient of the expansion device.

54. A method for expanding an expandable tubular member, comprising:

providing an expandable tubular member;  
providing an expansion device including an outer expansion surface;  
coating the outer expansion surface with a layer of material by laser-cladding;  
positioning the expansion device in the expandable tubular member; and  
expanding the expandable tubular member by displacing the expansion device through  
the expandable tubular member.

55. The method of claim 54, further comprising:

coating the layer of material with a diamond coating.

56. The method of claim 54, further comprising:

reducing the coefficient of friction between the expandable tubular member and the expansion device by coating the layer of material with a diamond coating.



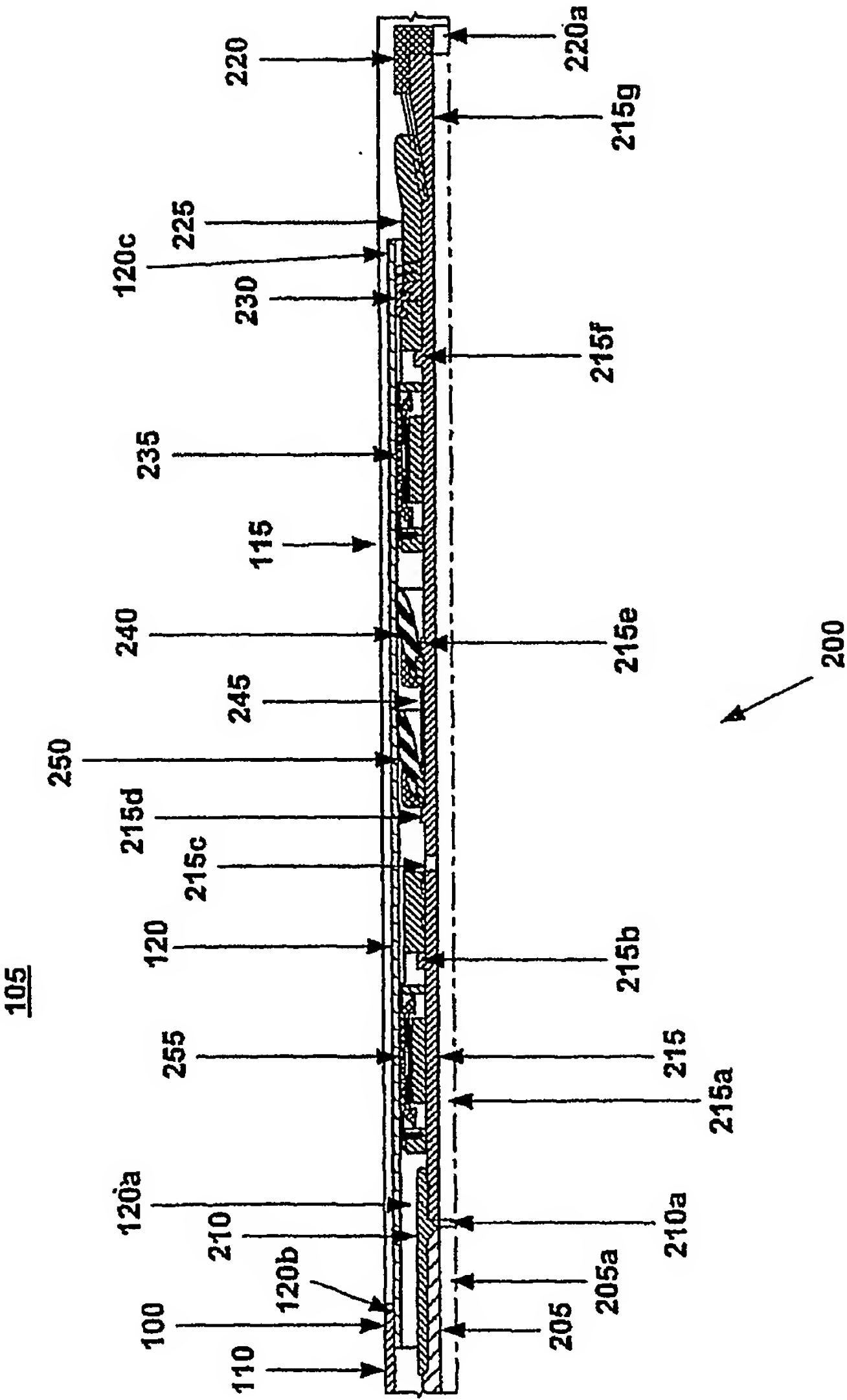


Fig. 1

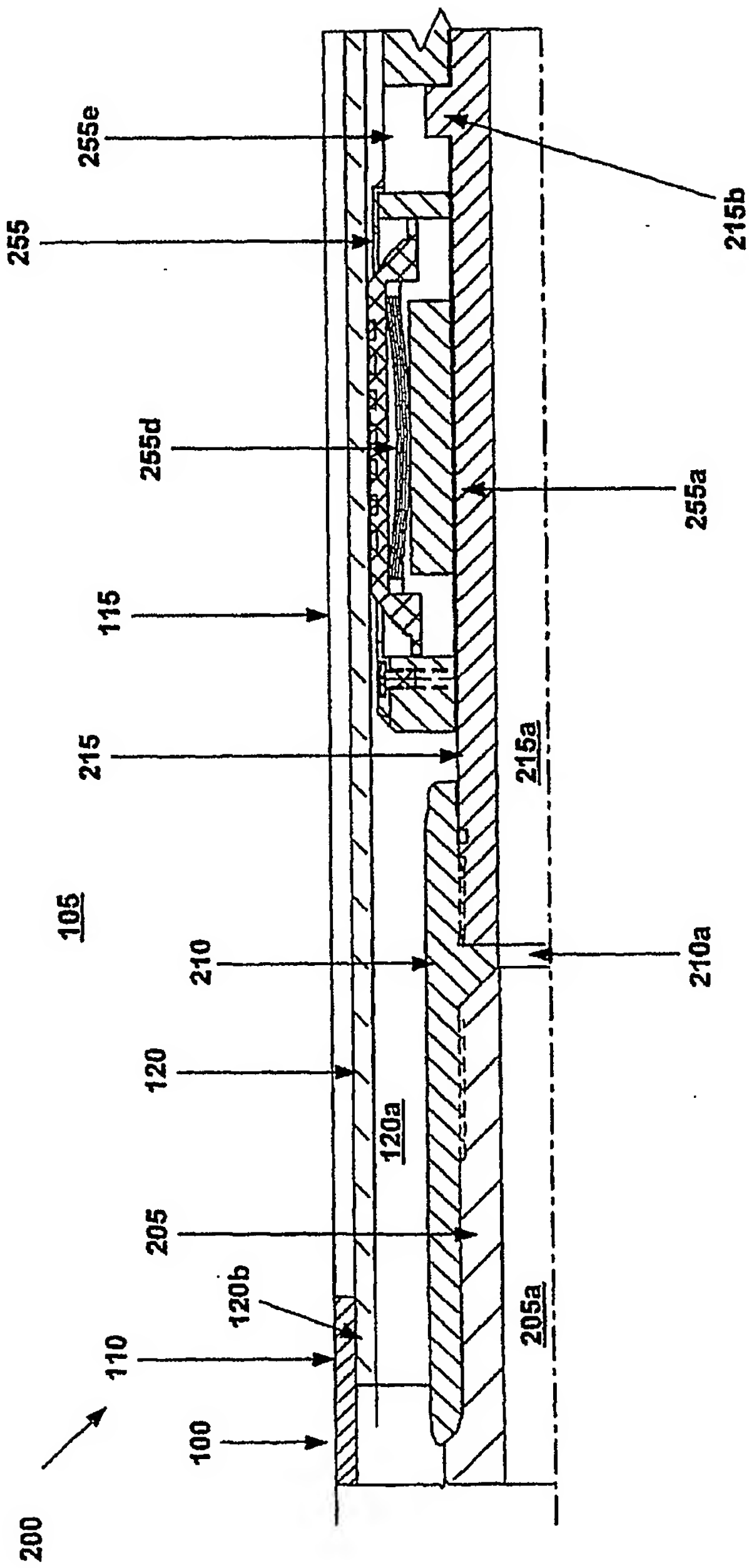


Fig. 1a

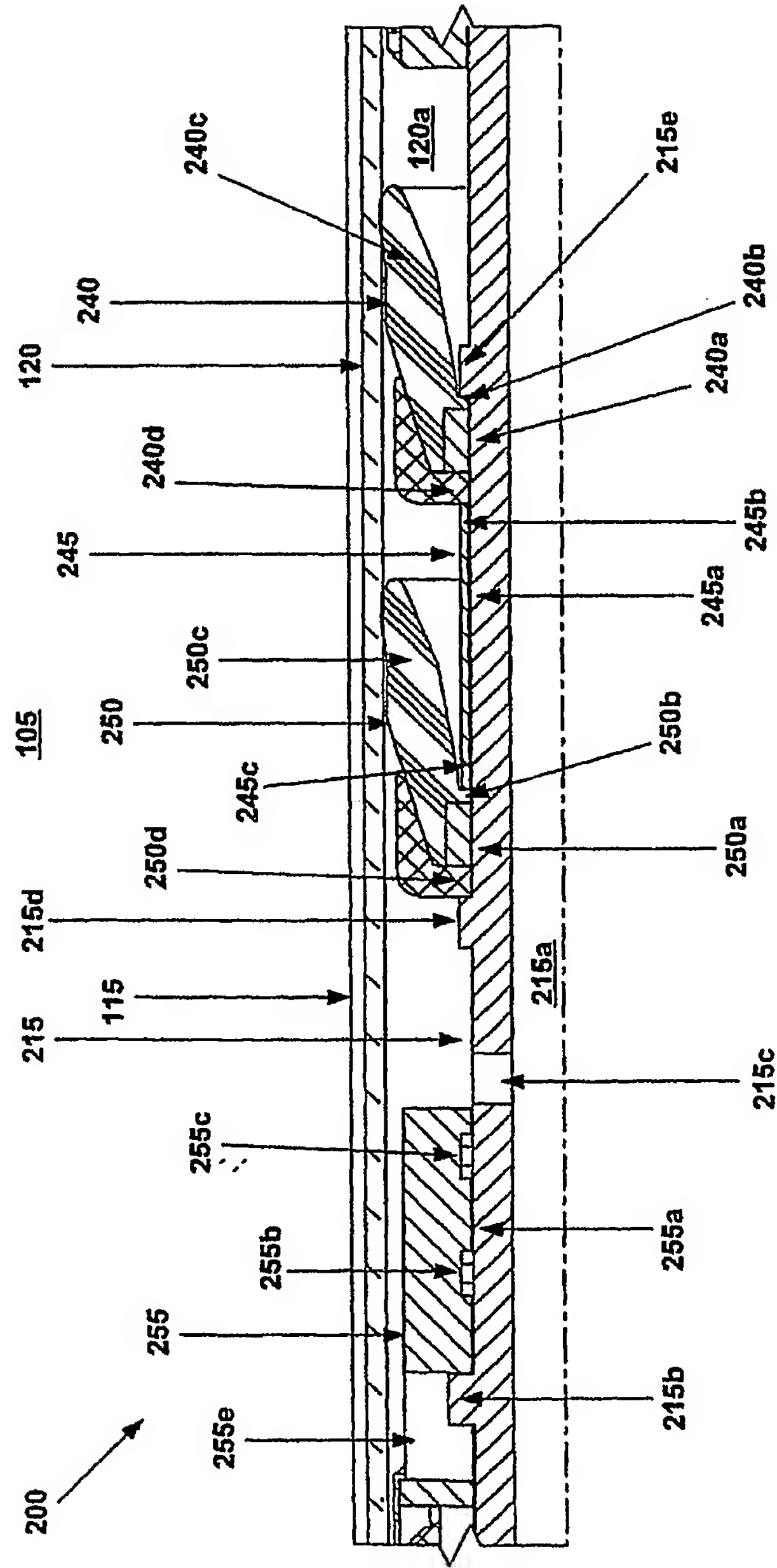
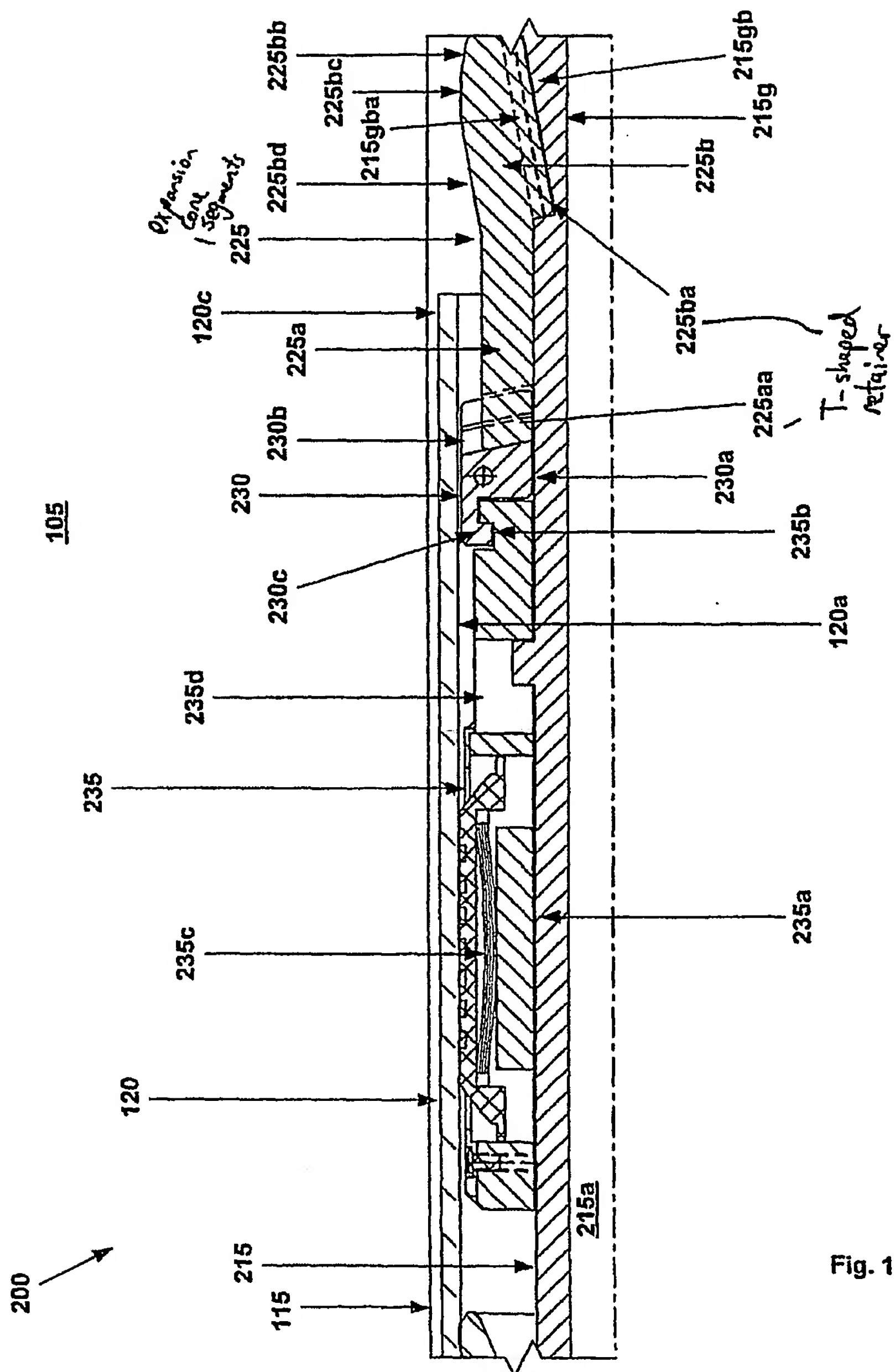


Fig. 1b



**Fig. 1c**





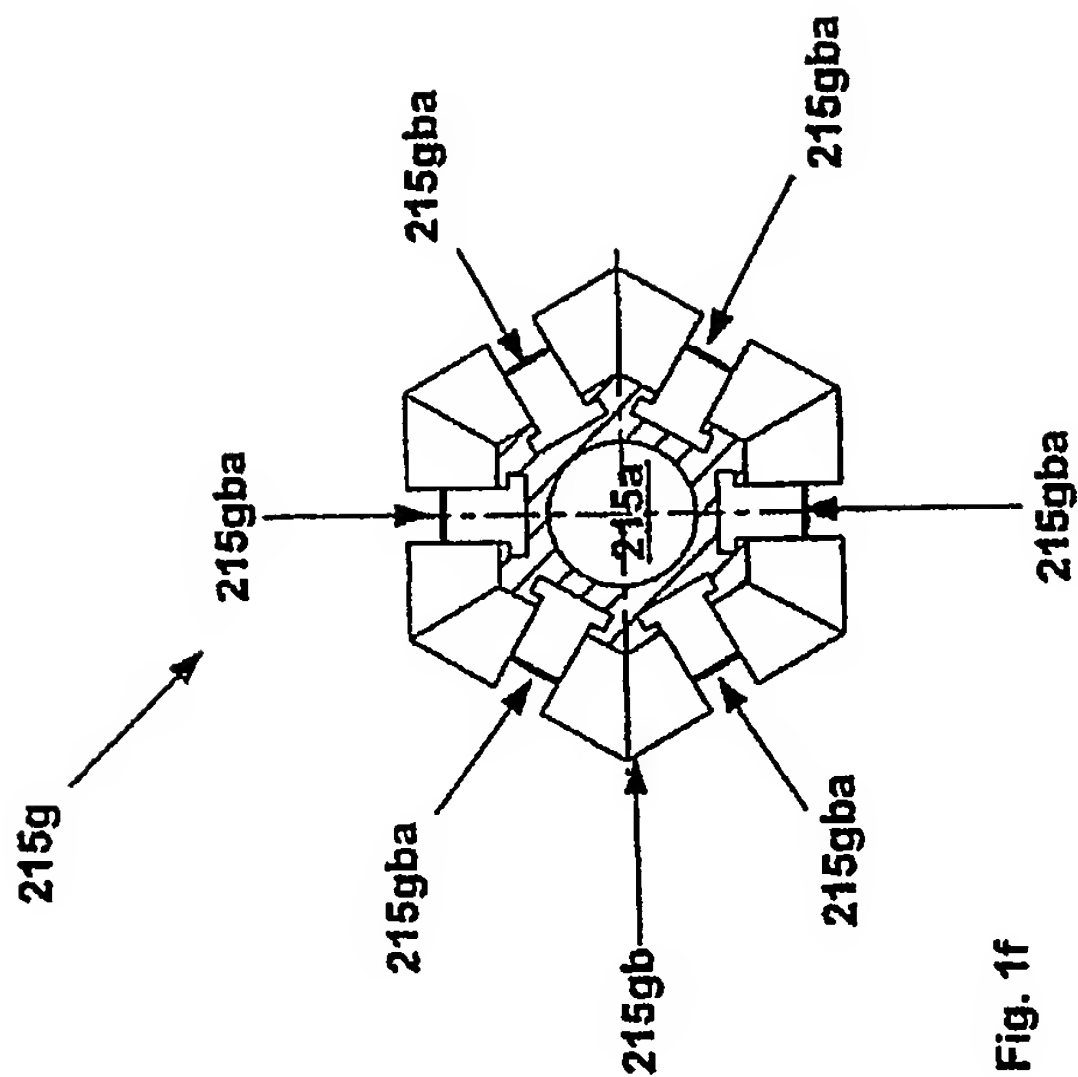


Fig. 1f

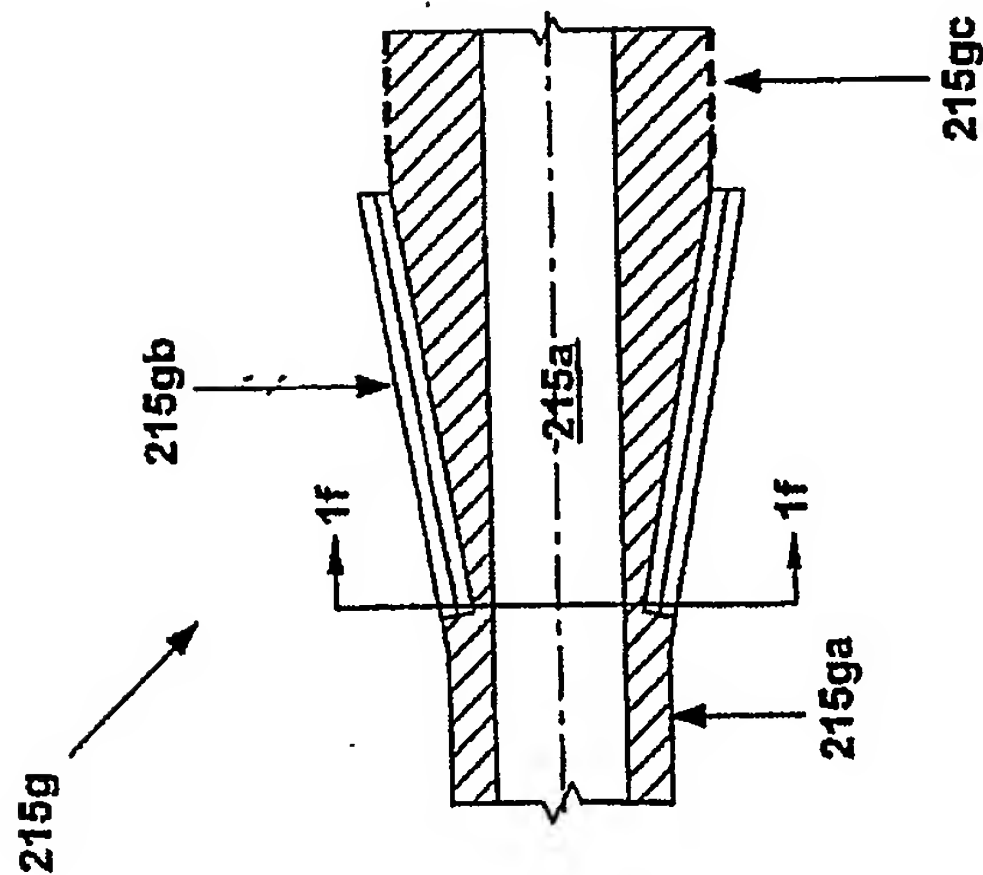
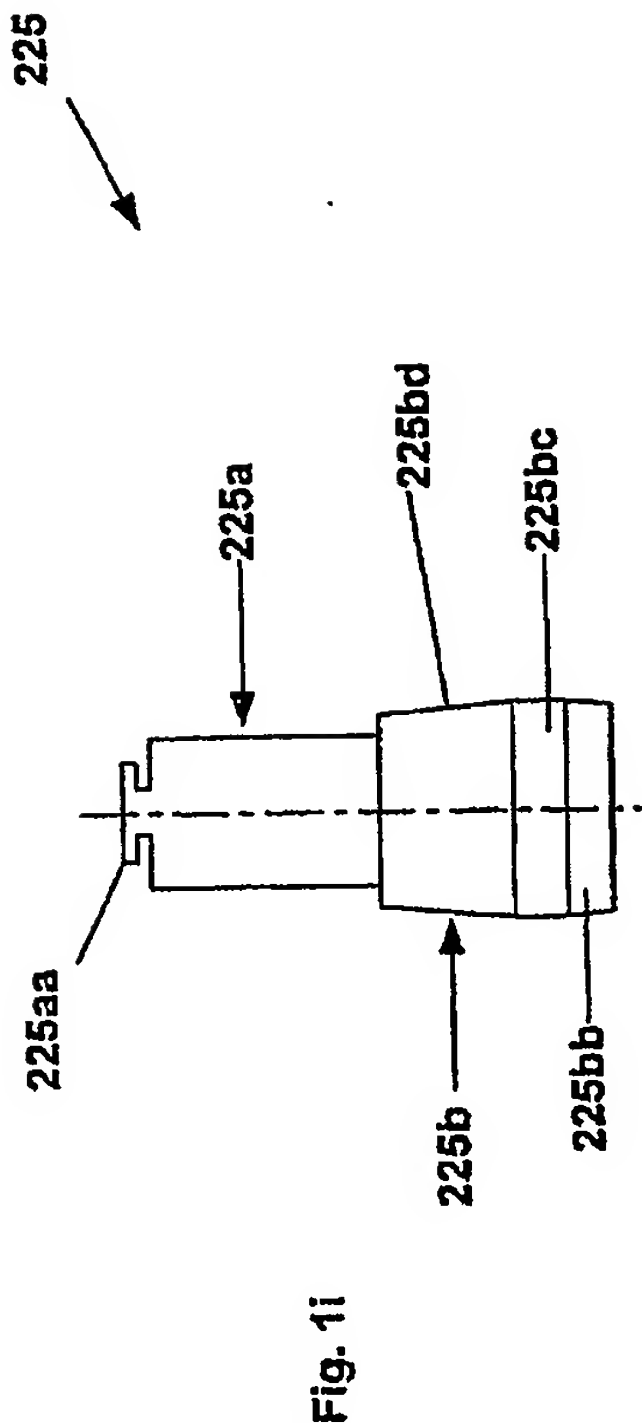
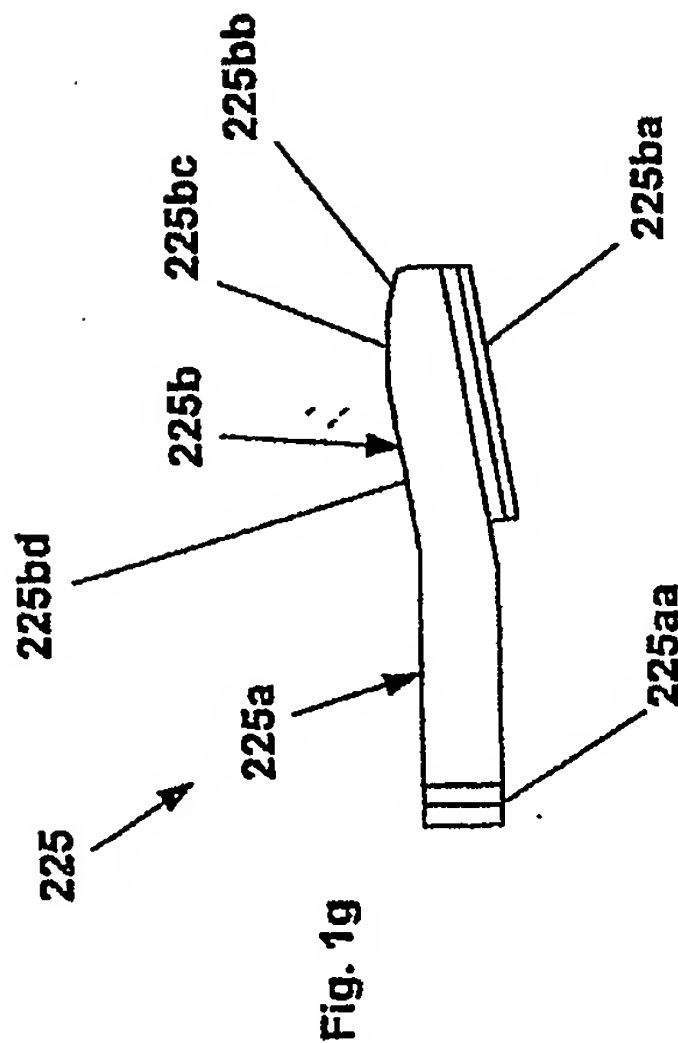
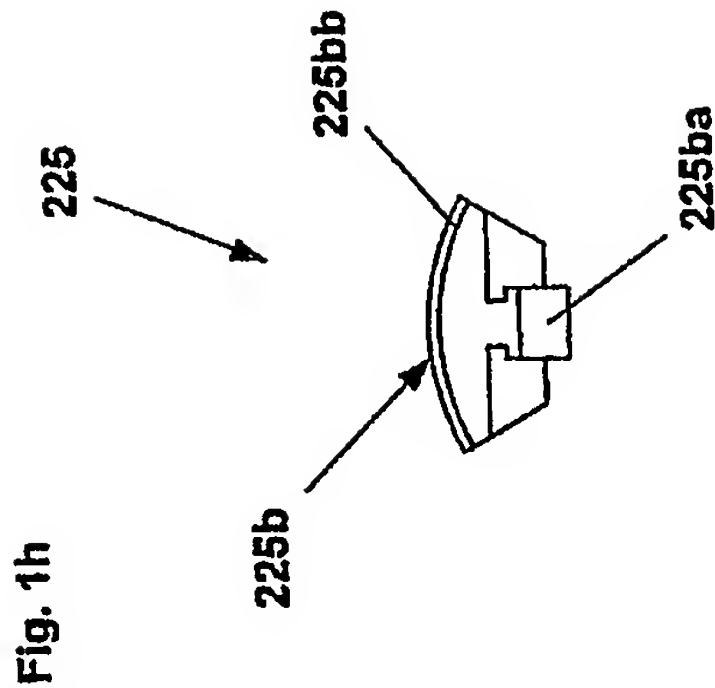


Fig. 1e



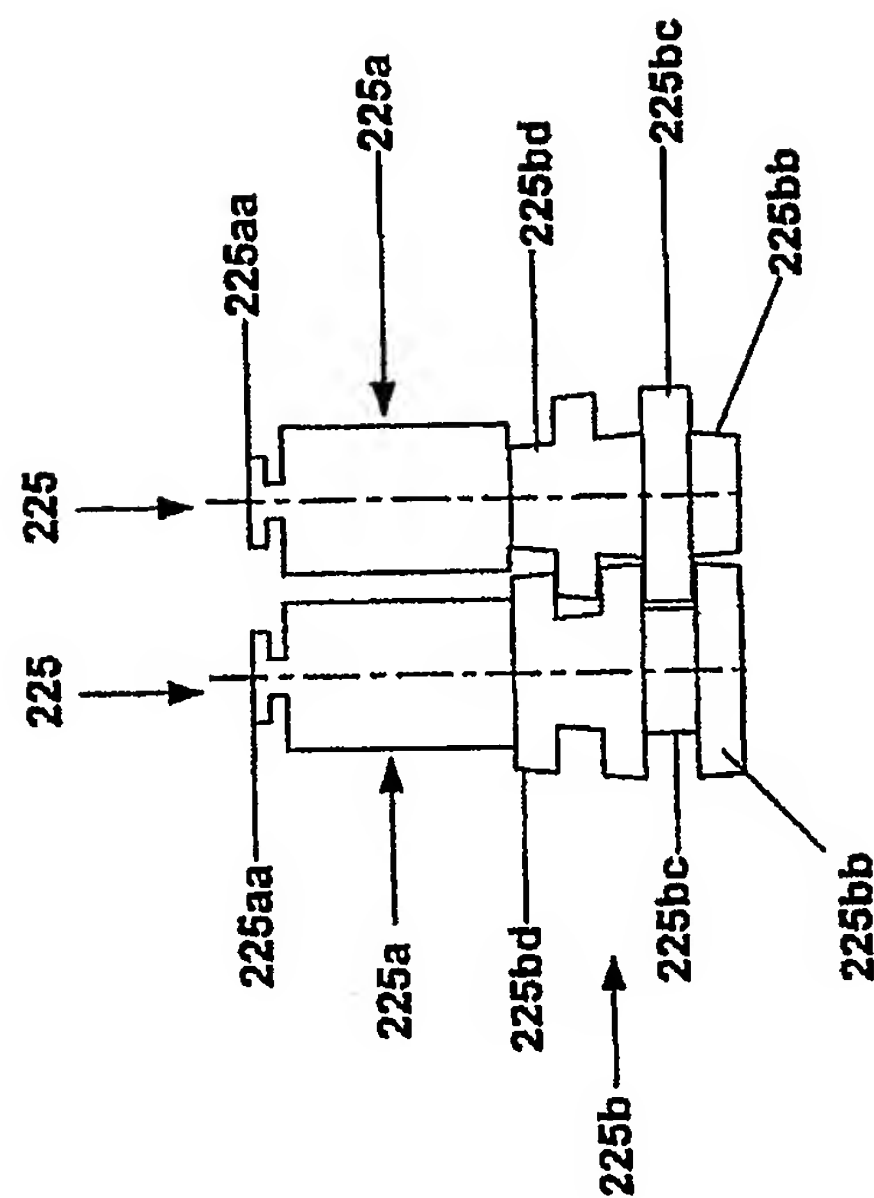


Fig. 1j



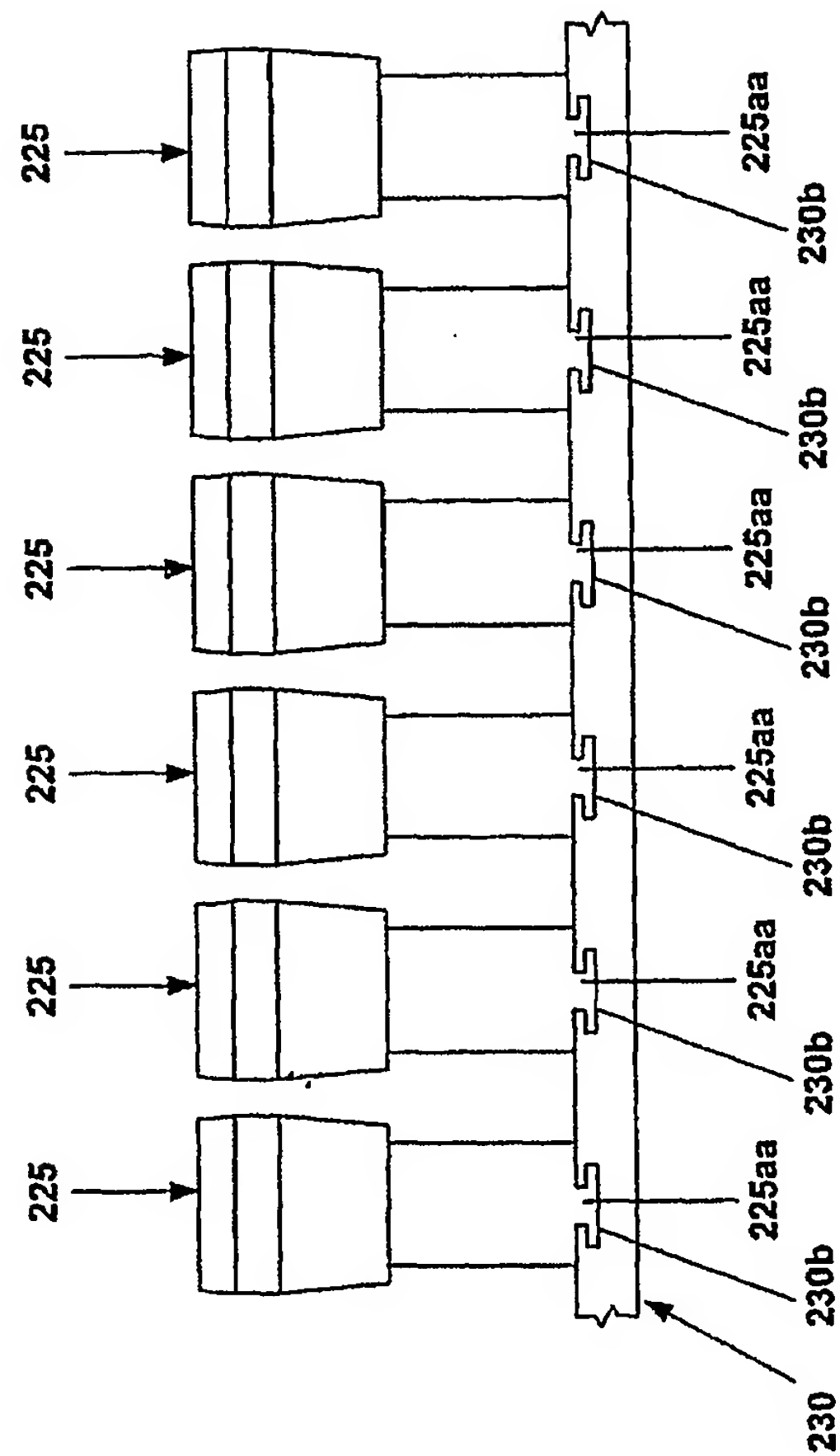


Fig. 1k

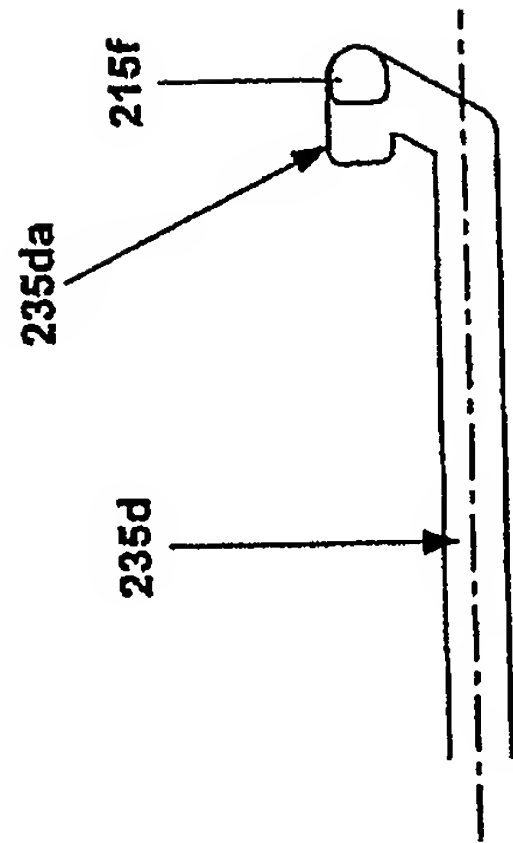


Fig. 1m

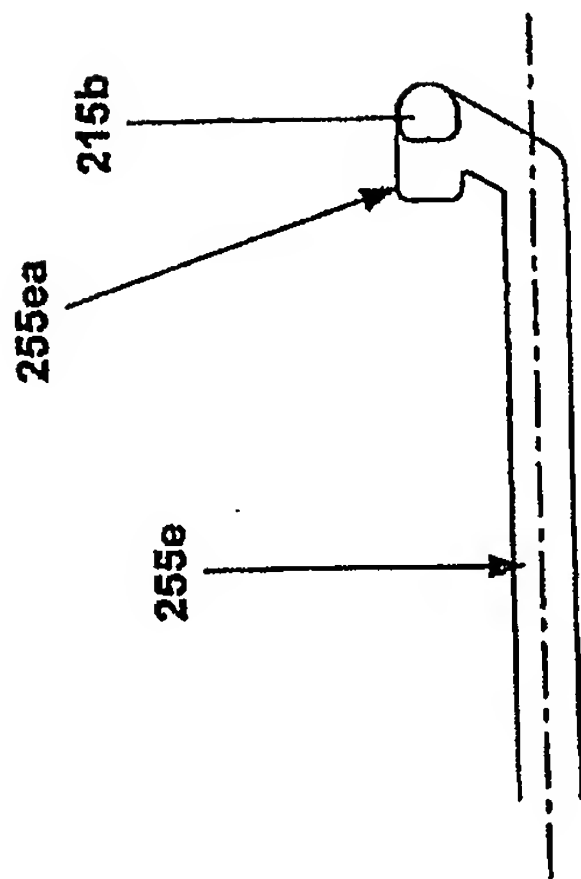


Fig. 1l

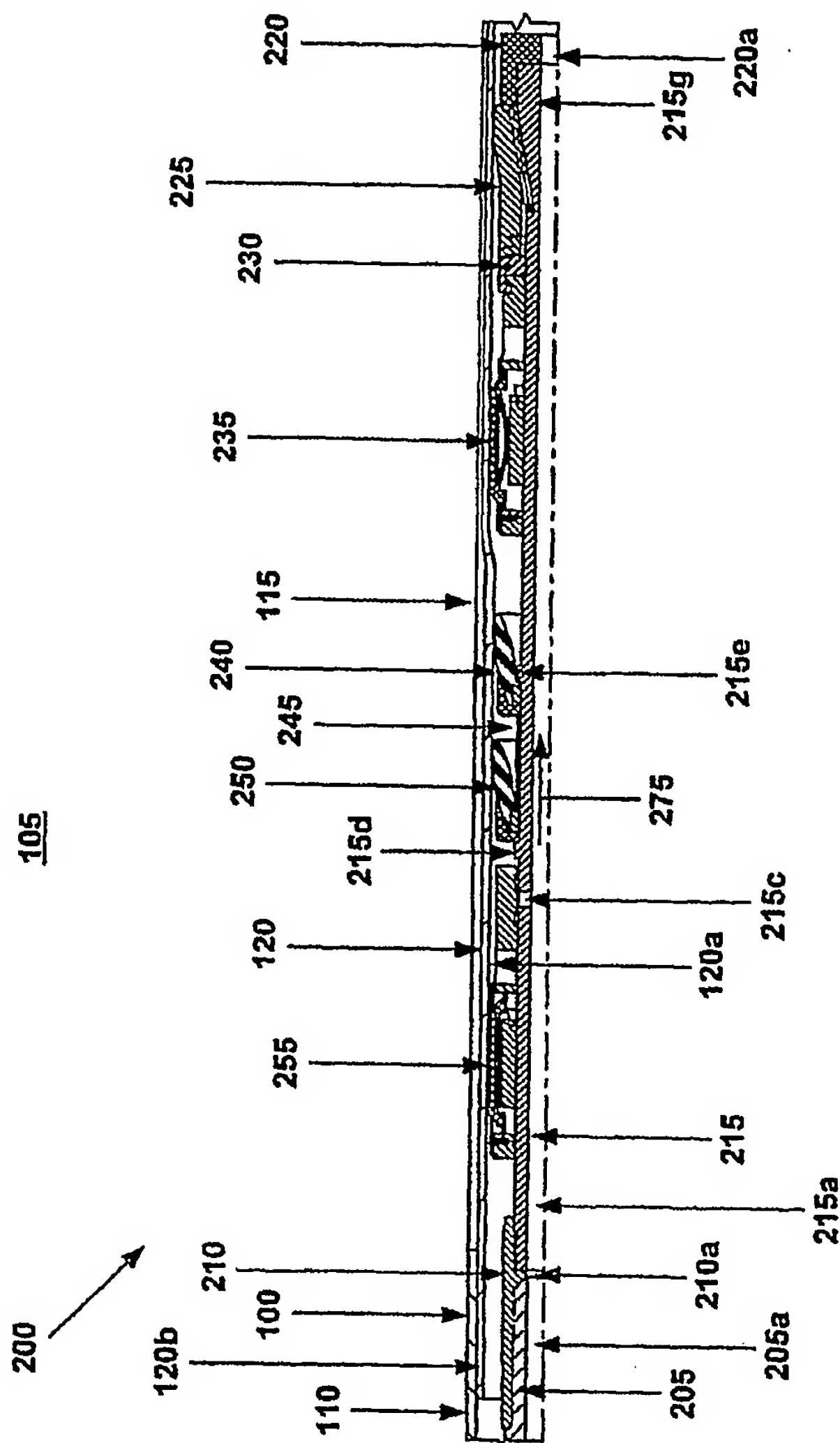


Fig. 2

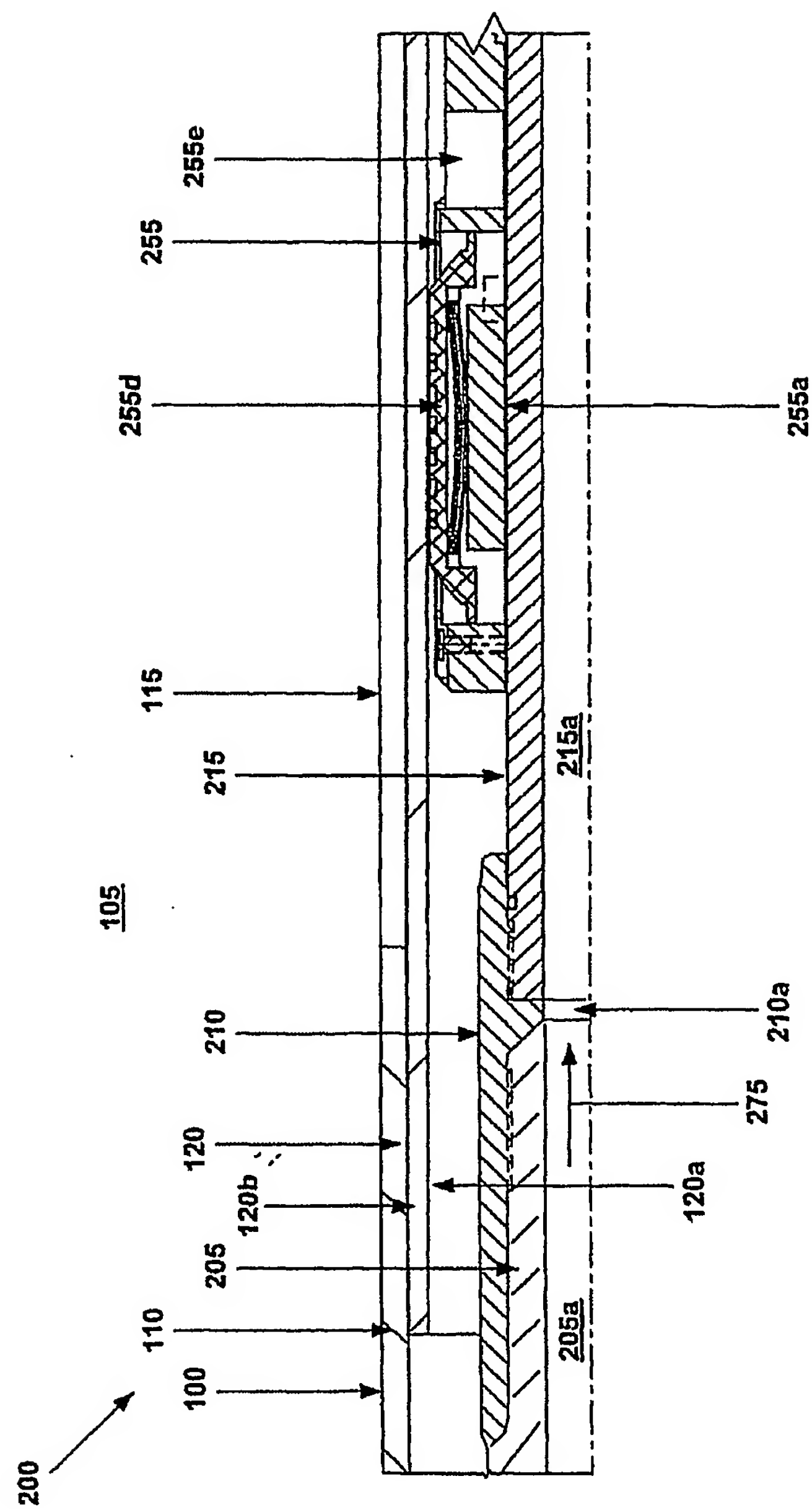
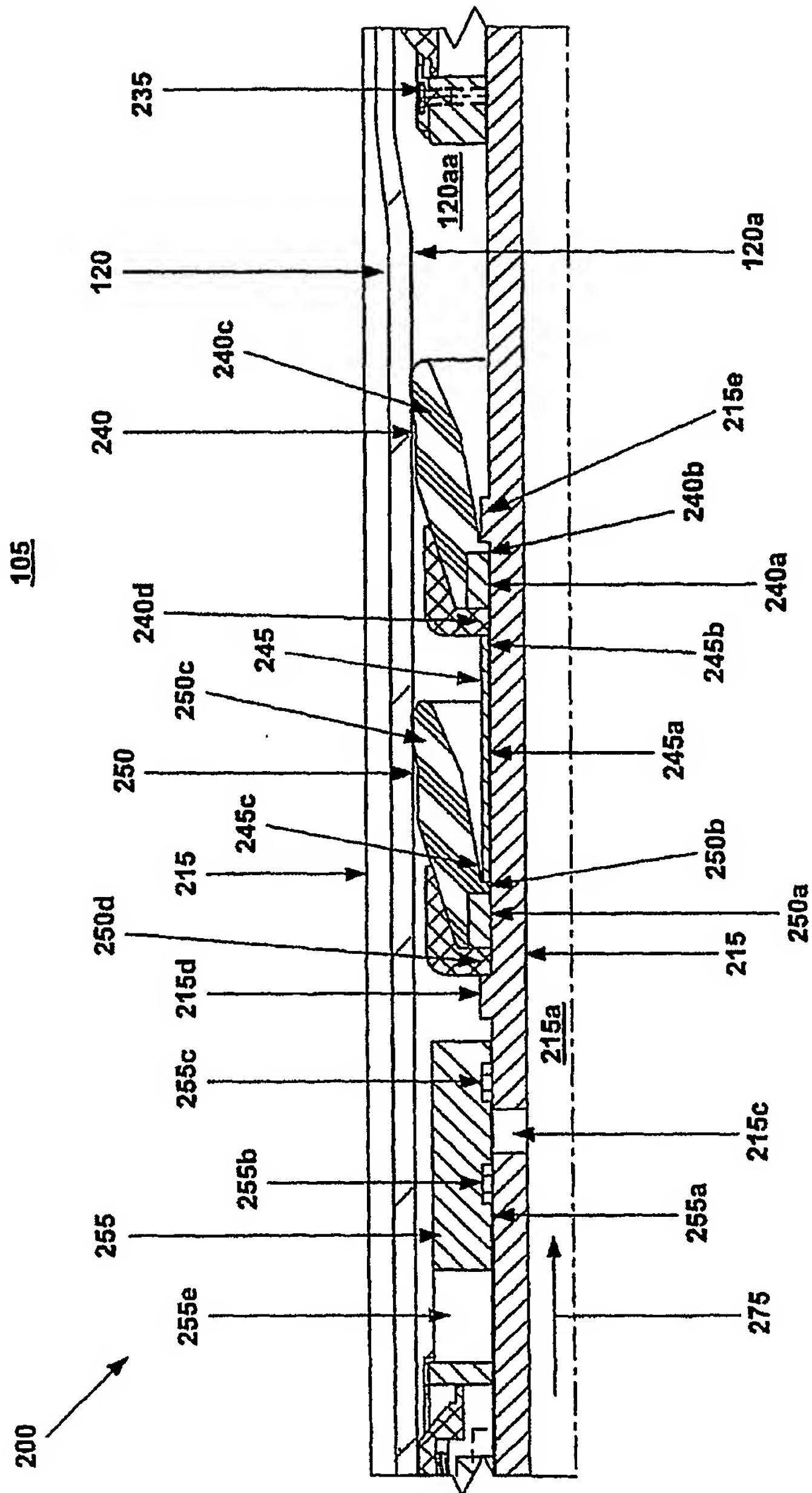


Fig. 2a





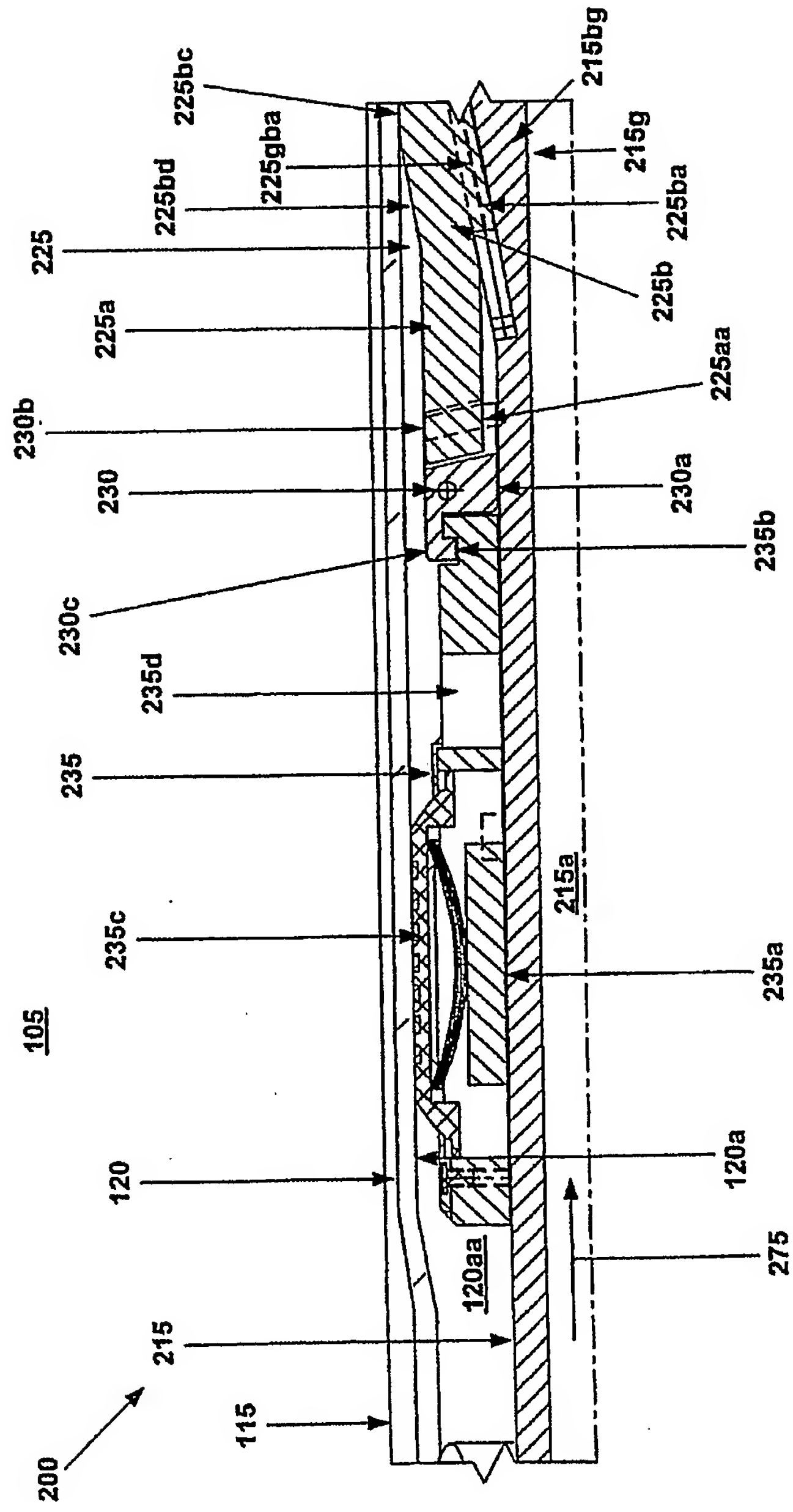


Fig. 2c

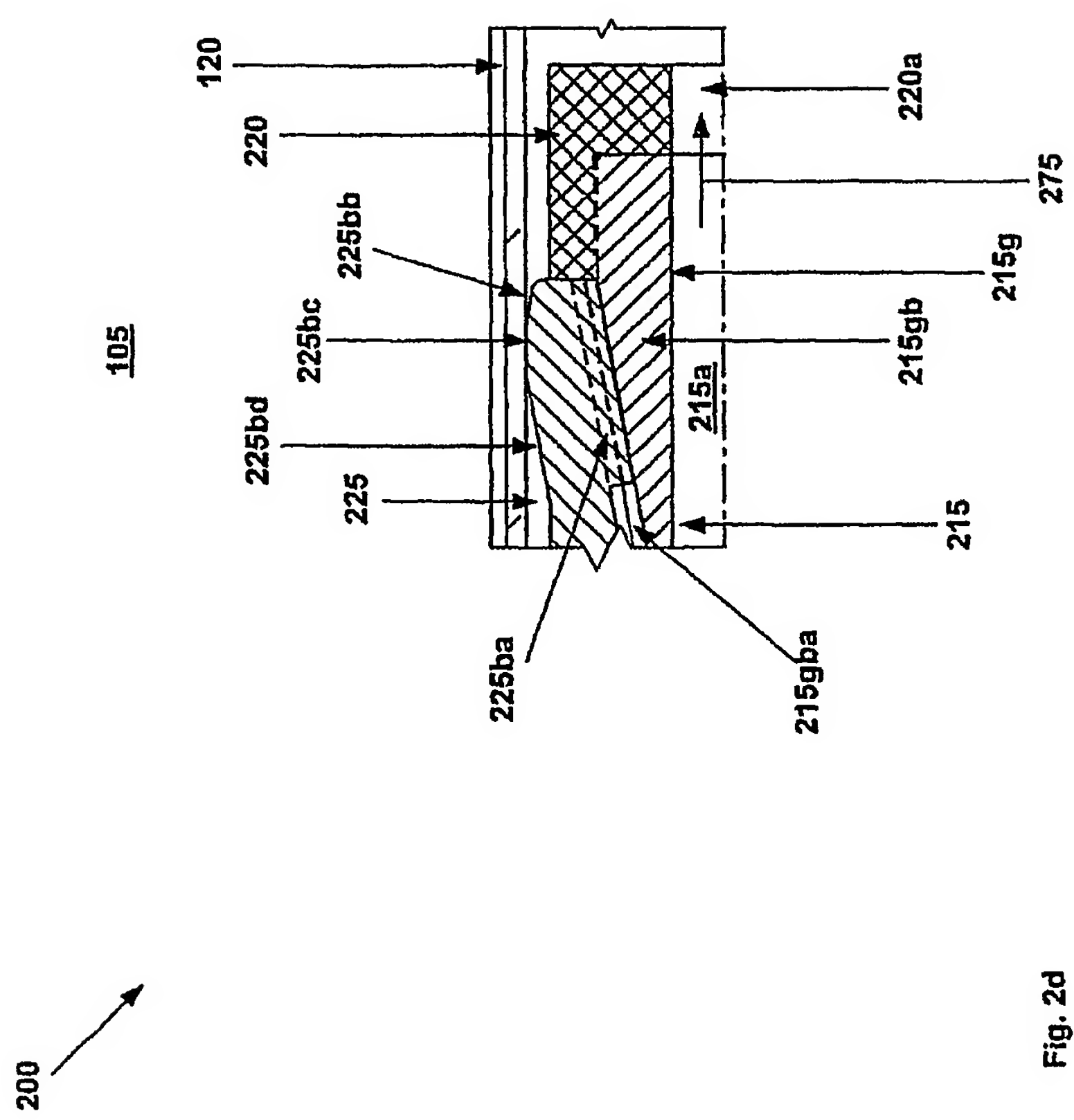


Fig. 2d

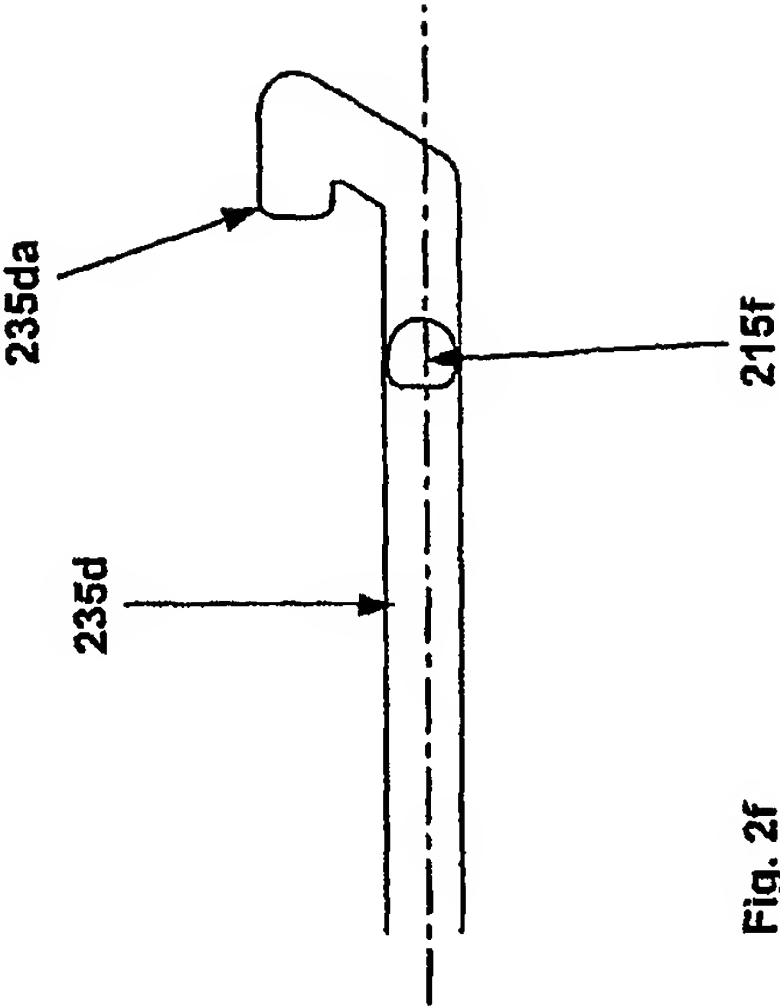


Fig. 2f

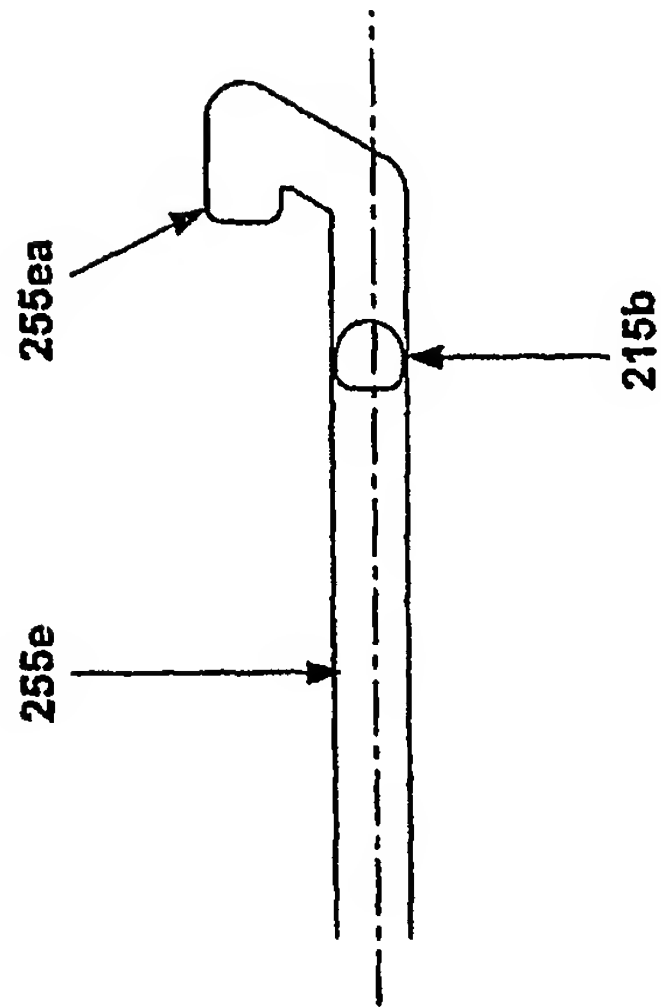


Fig. 2e



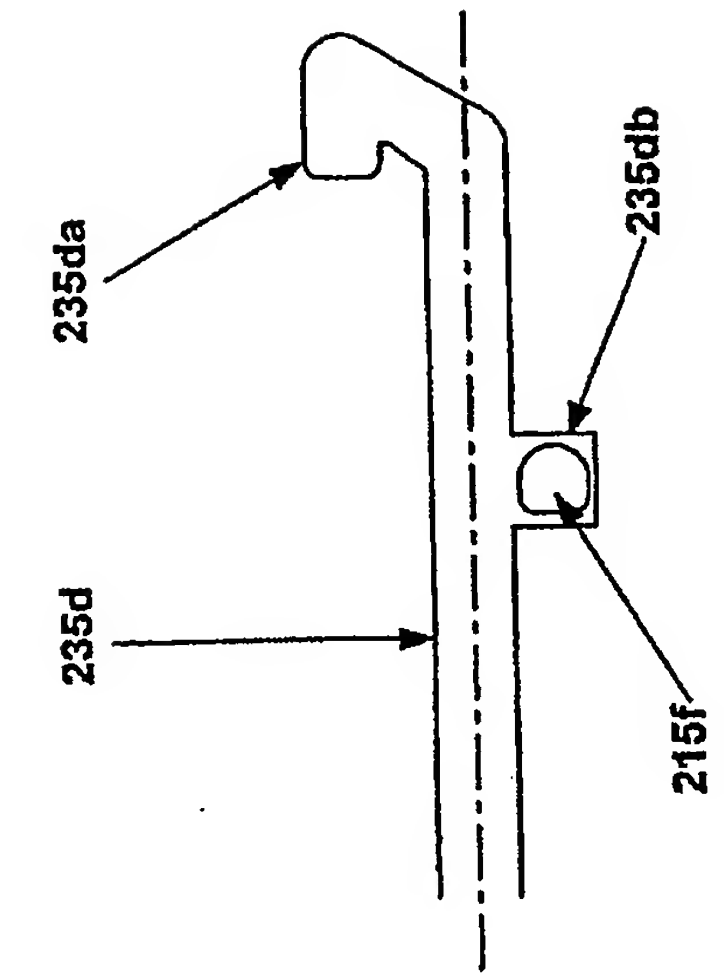


Fig. 2h

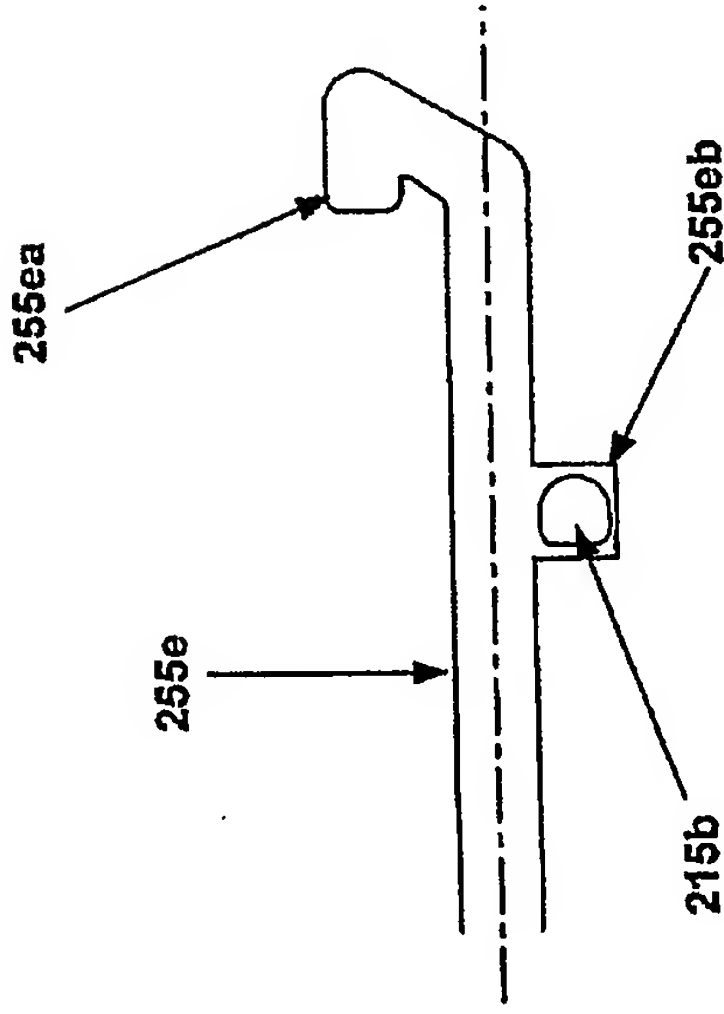


Fig. 2g

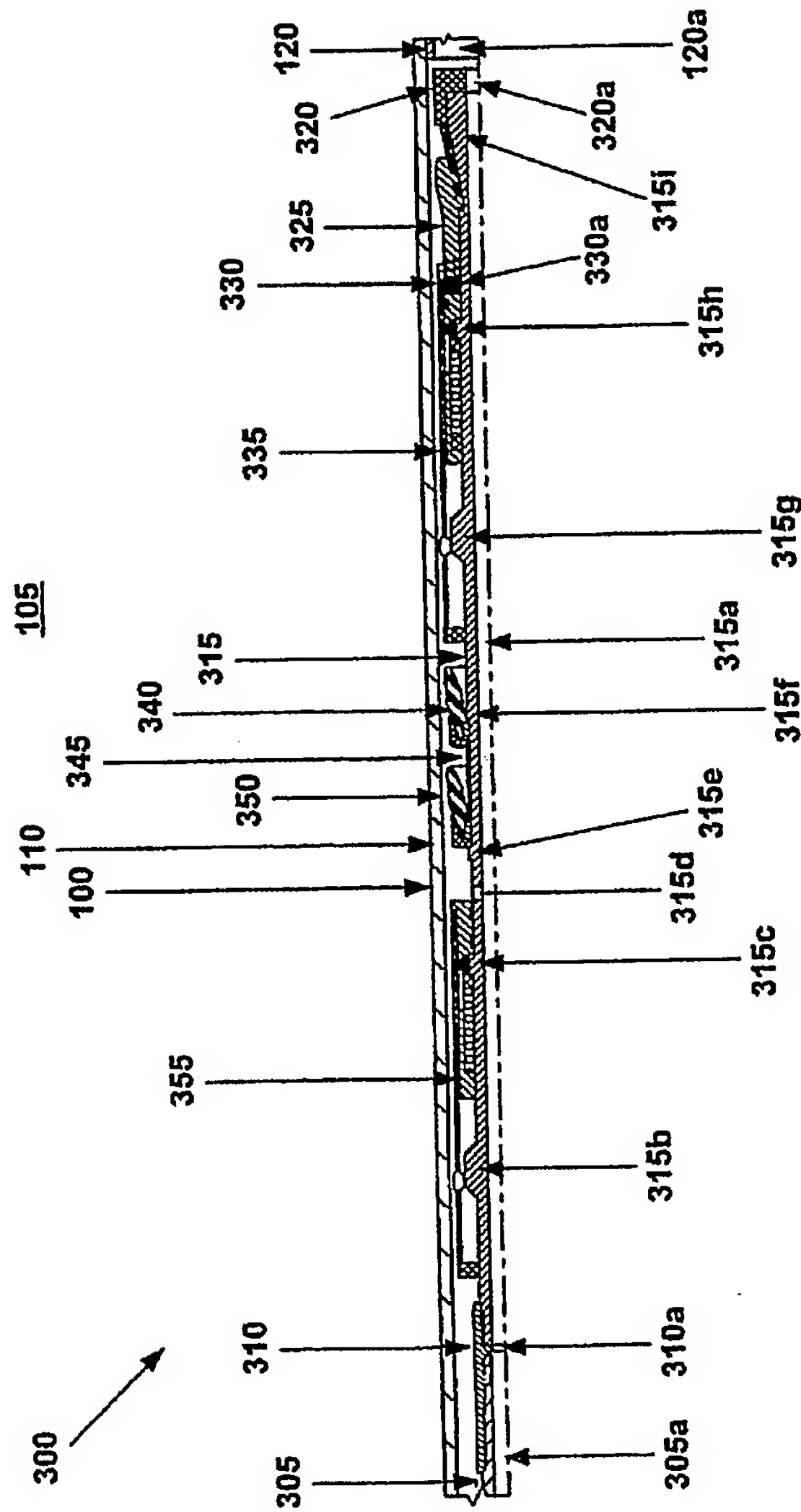
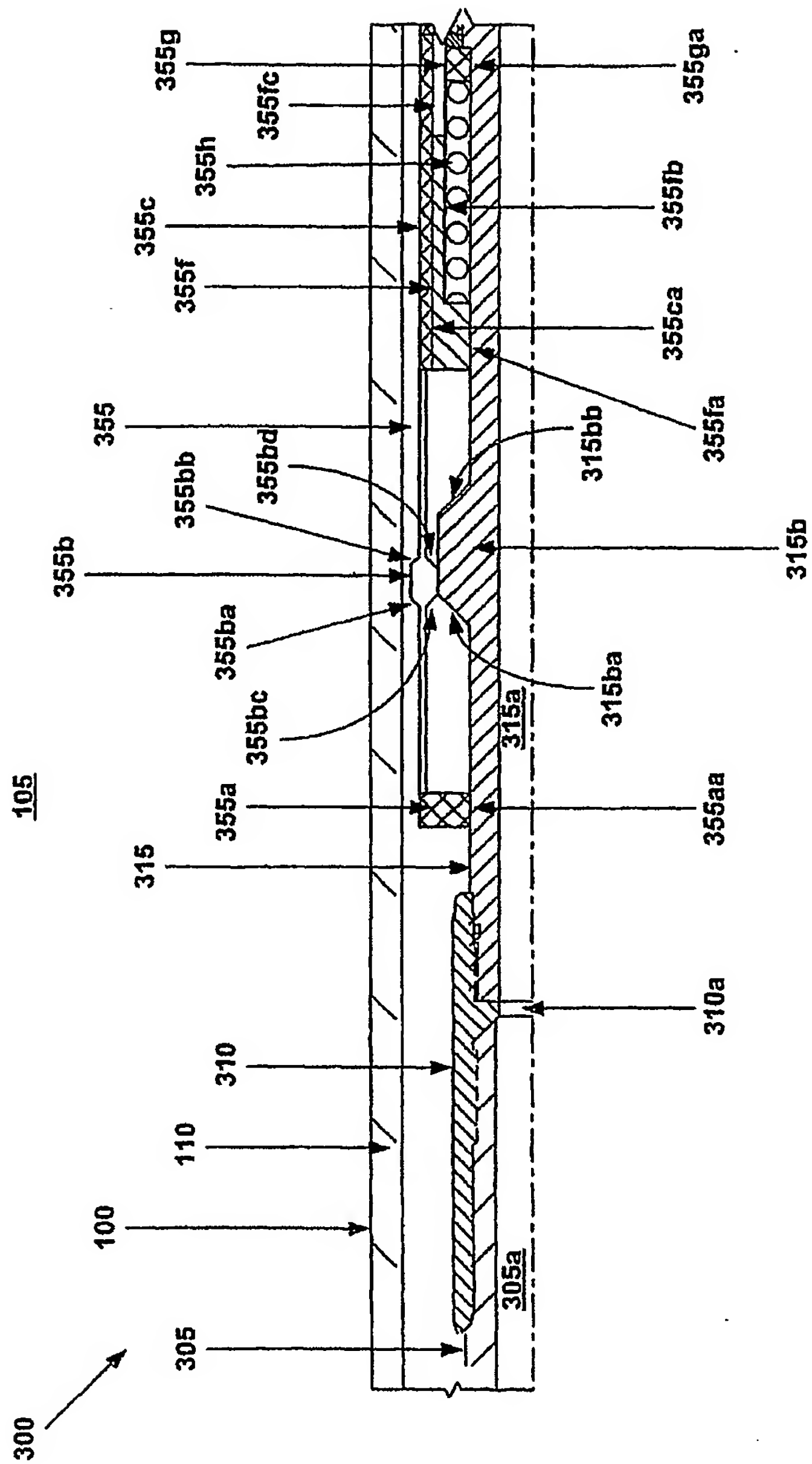


Fig. 3



**Fig. 3a**

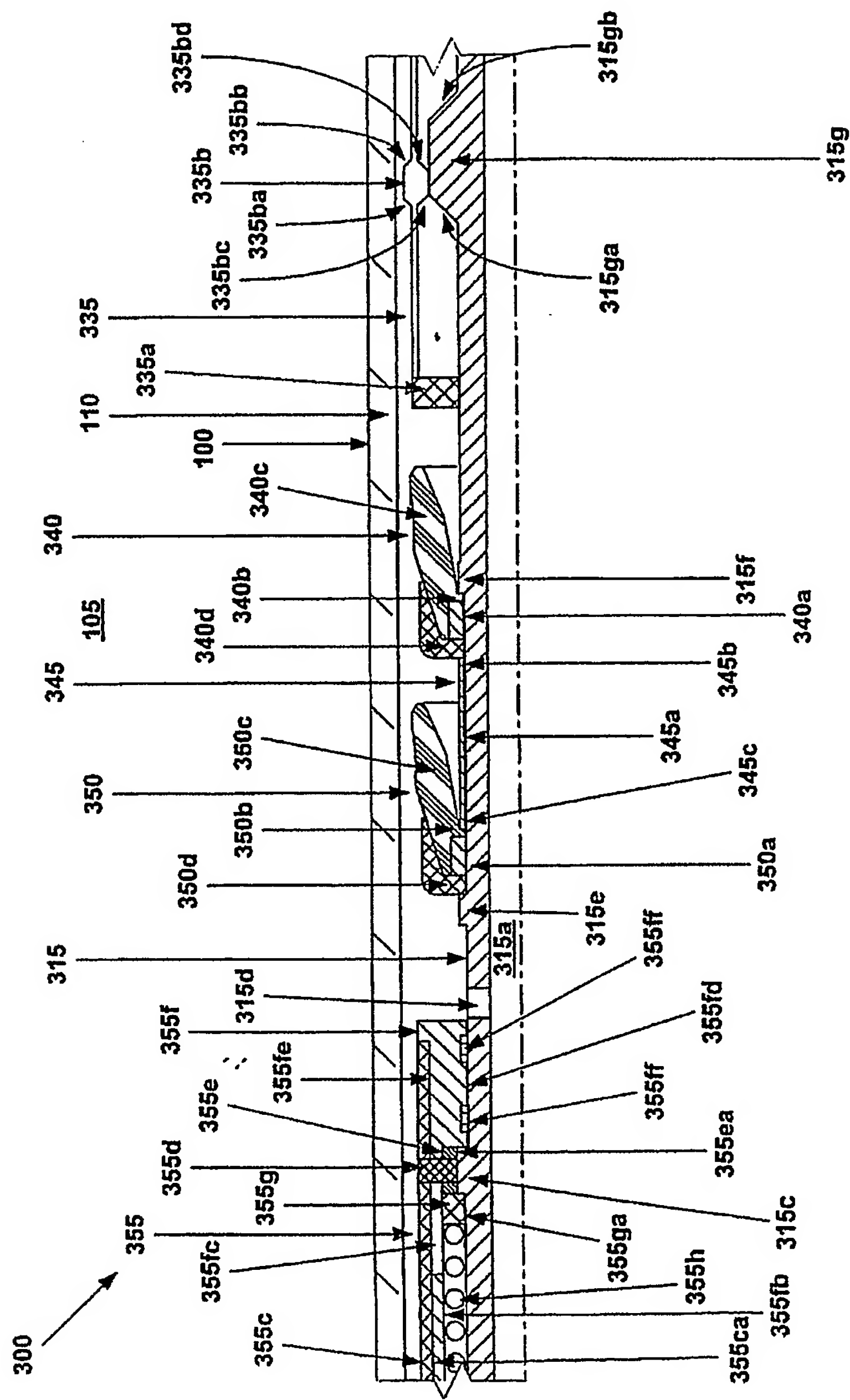


Fig. 3b



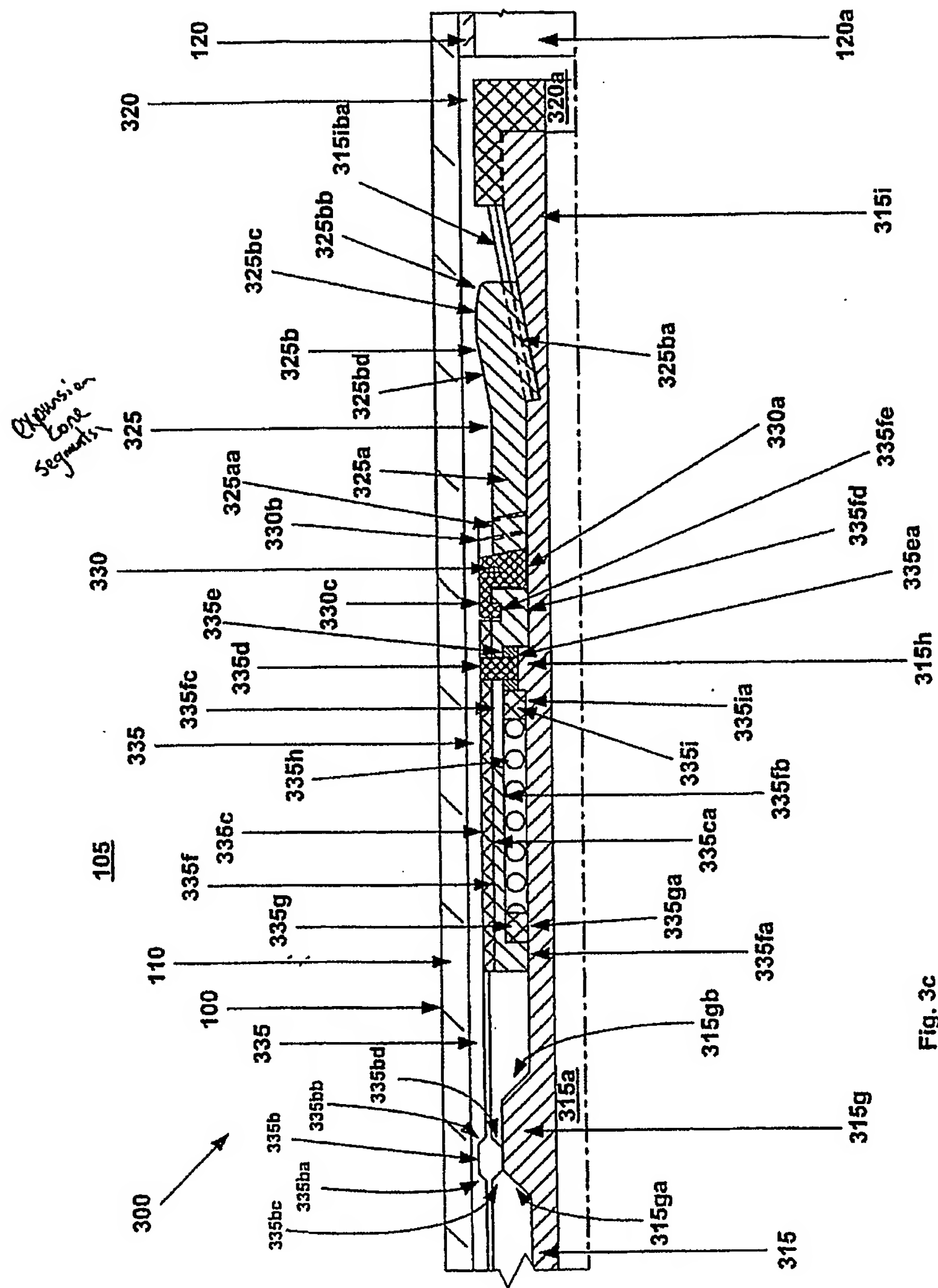
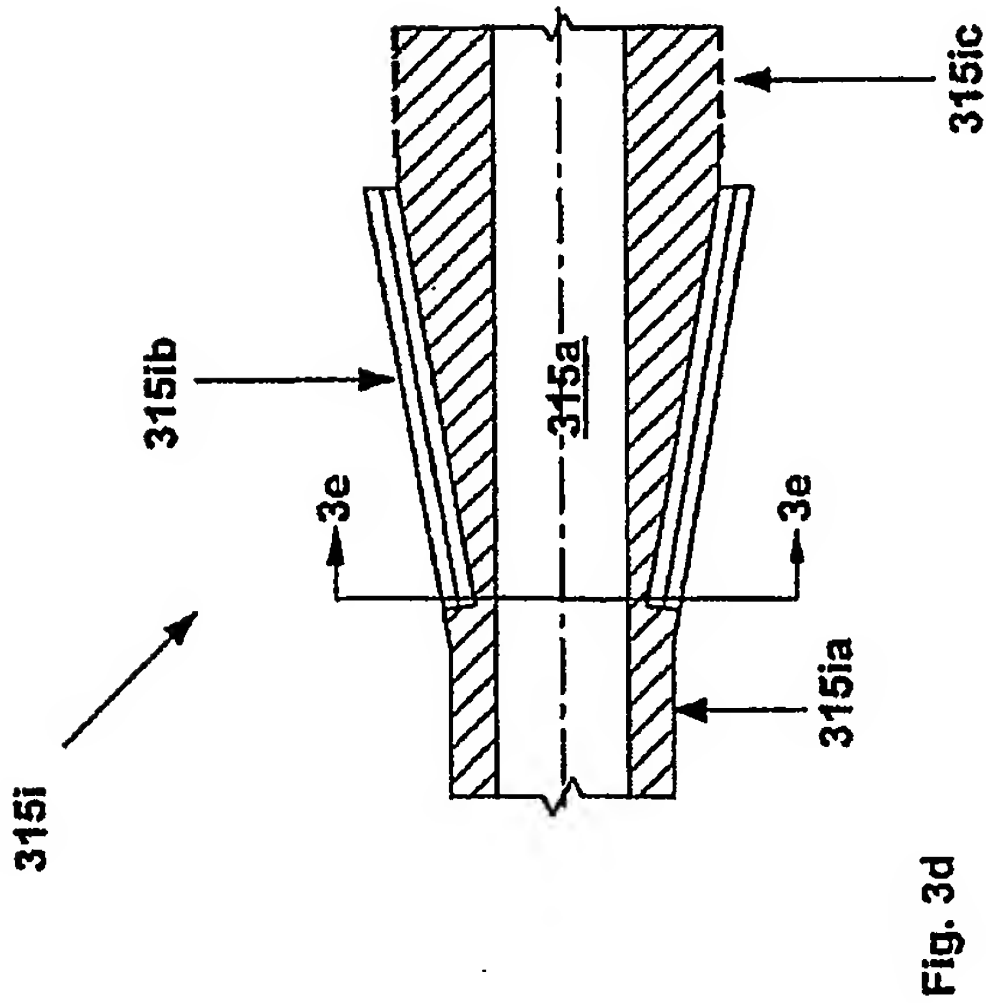
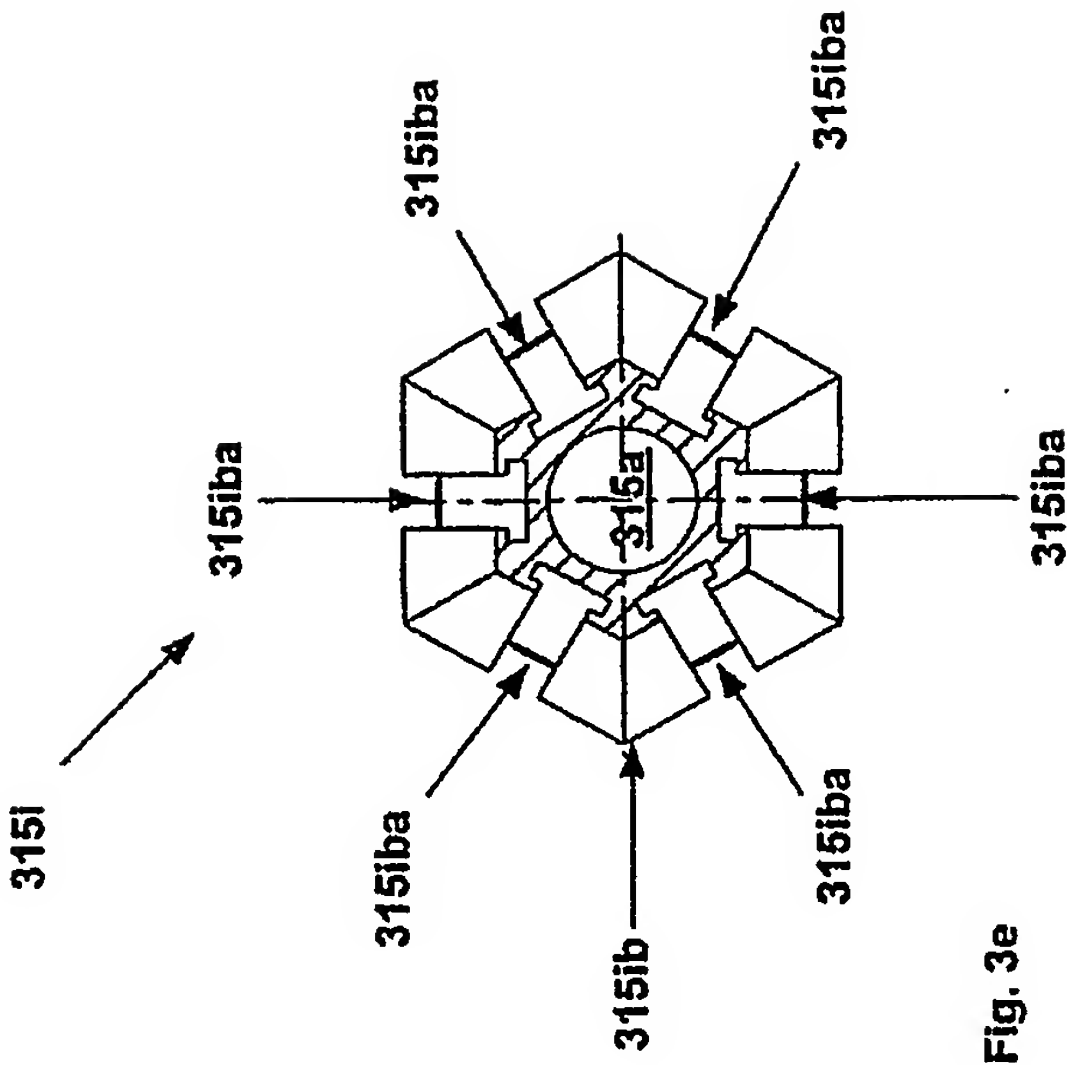


Fig. 3c



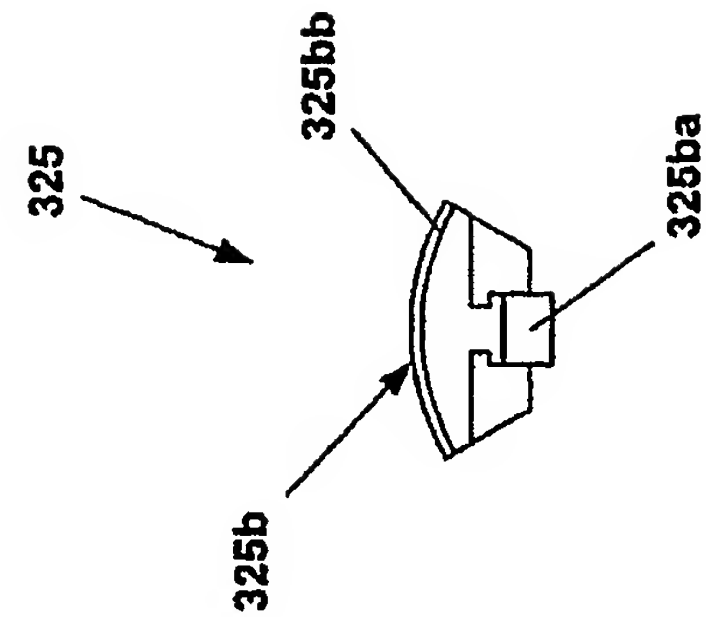


Fig. 3g

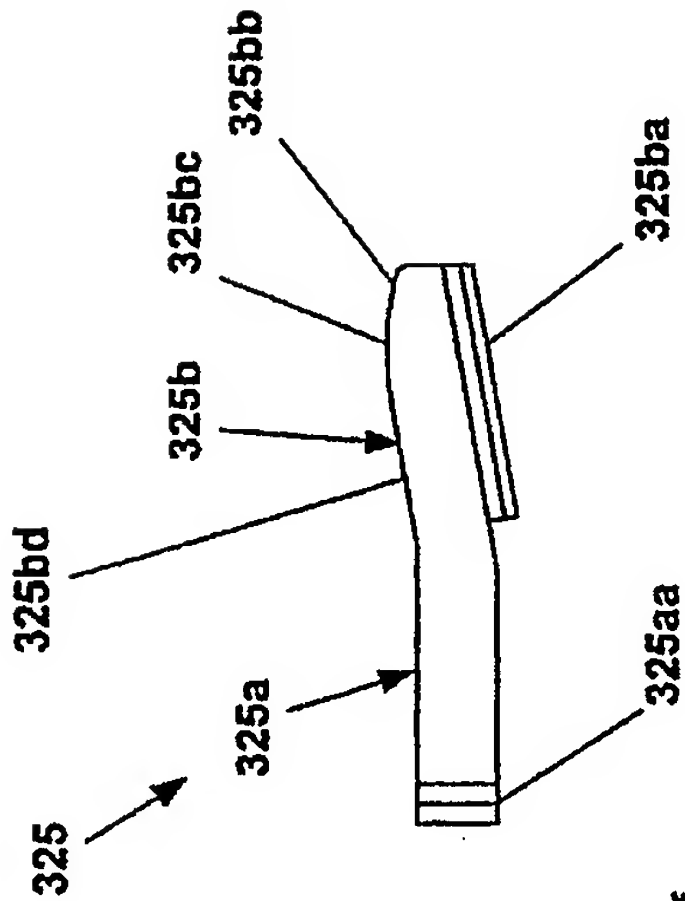


Fig. 3f

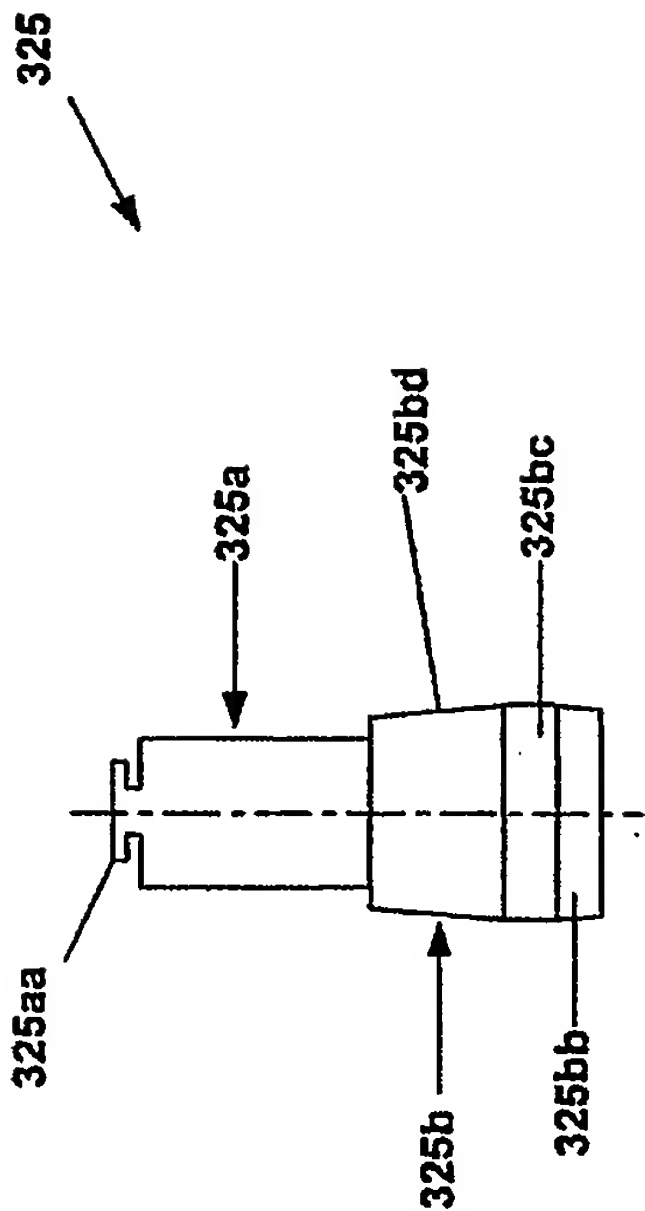


Fig. 3h

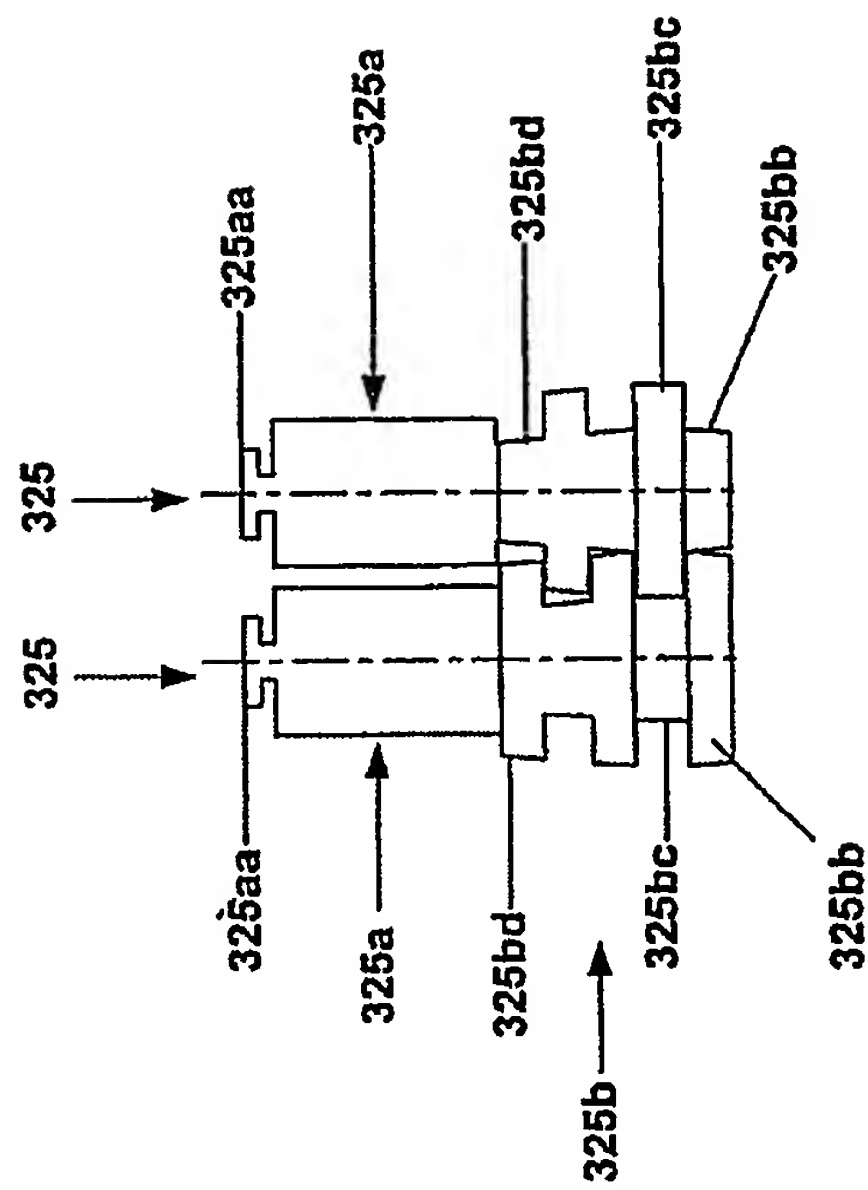


Fig. 3i

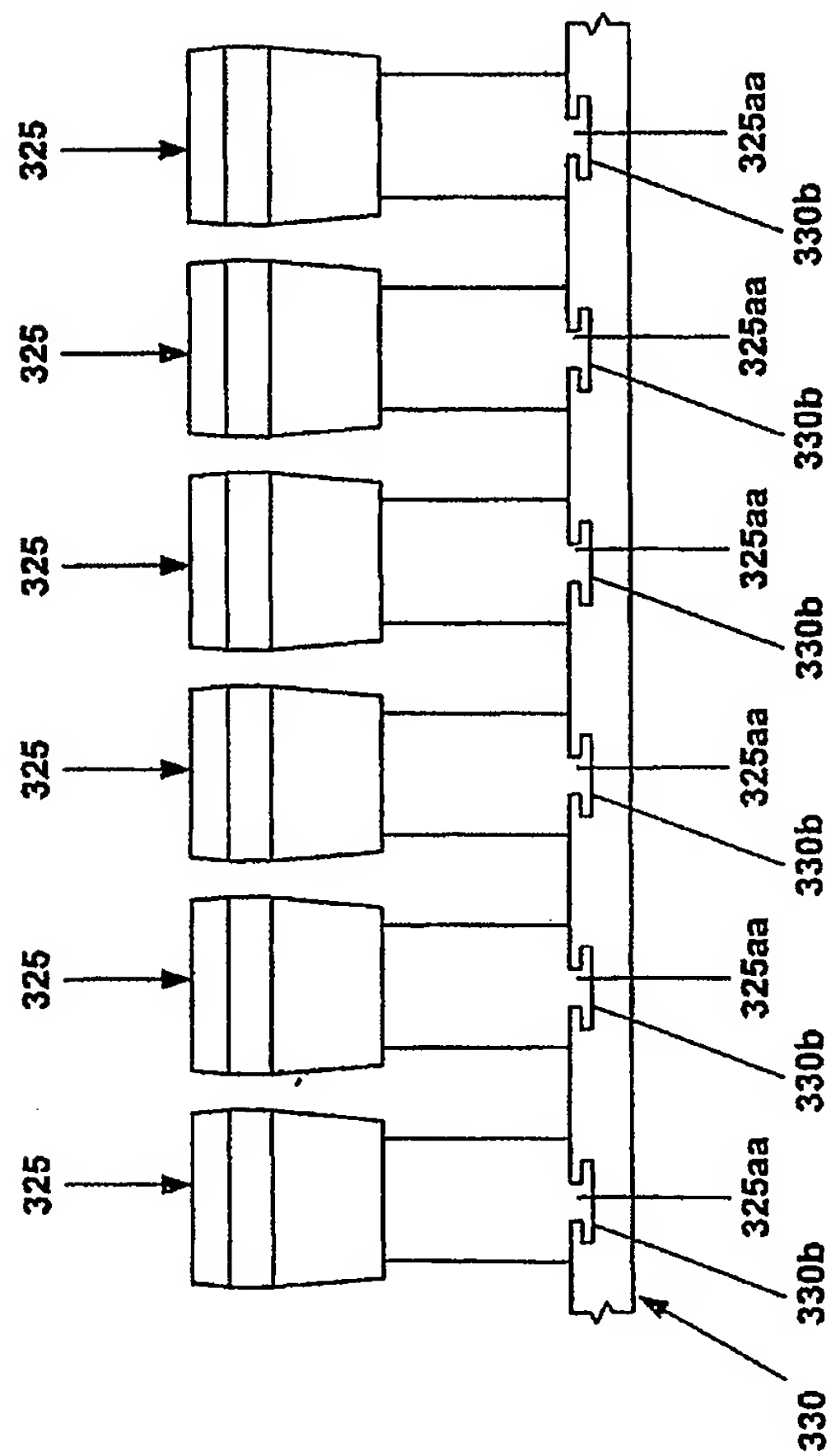
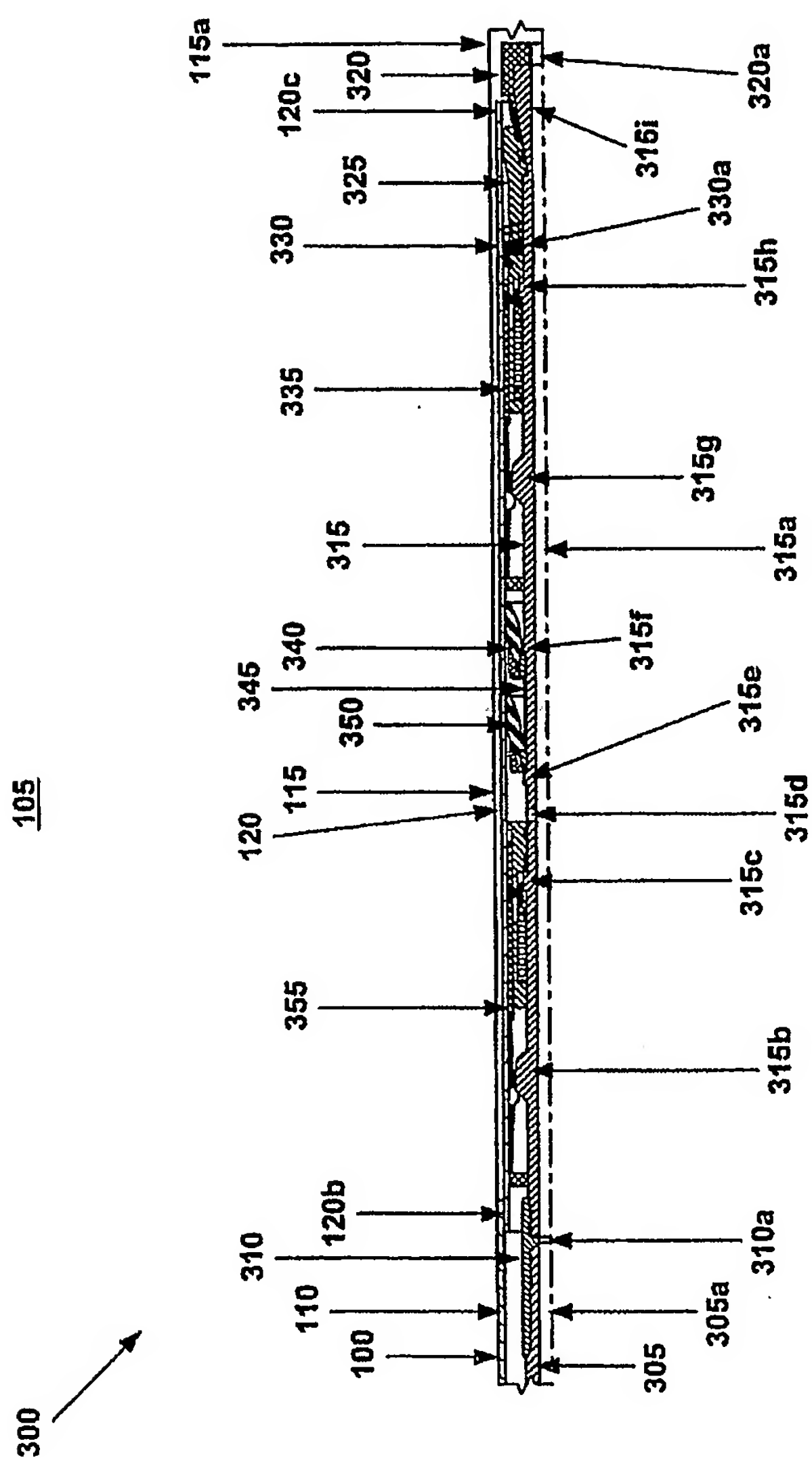
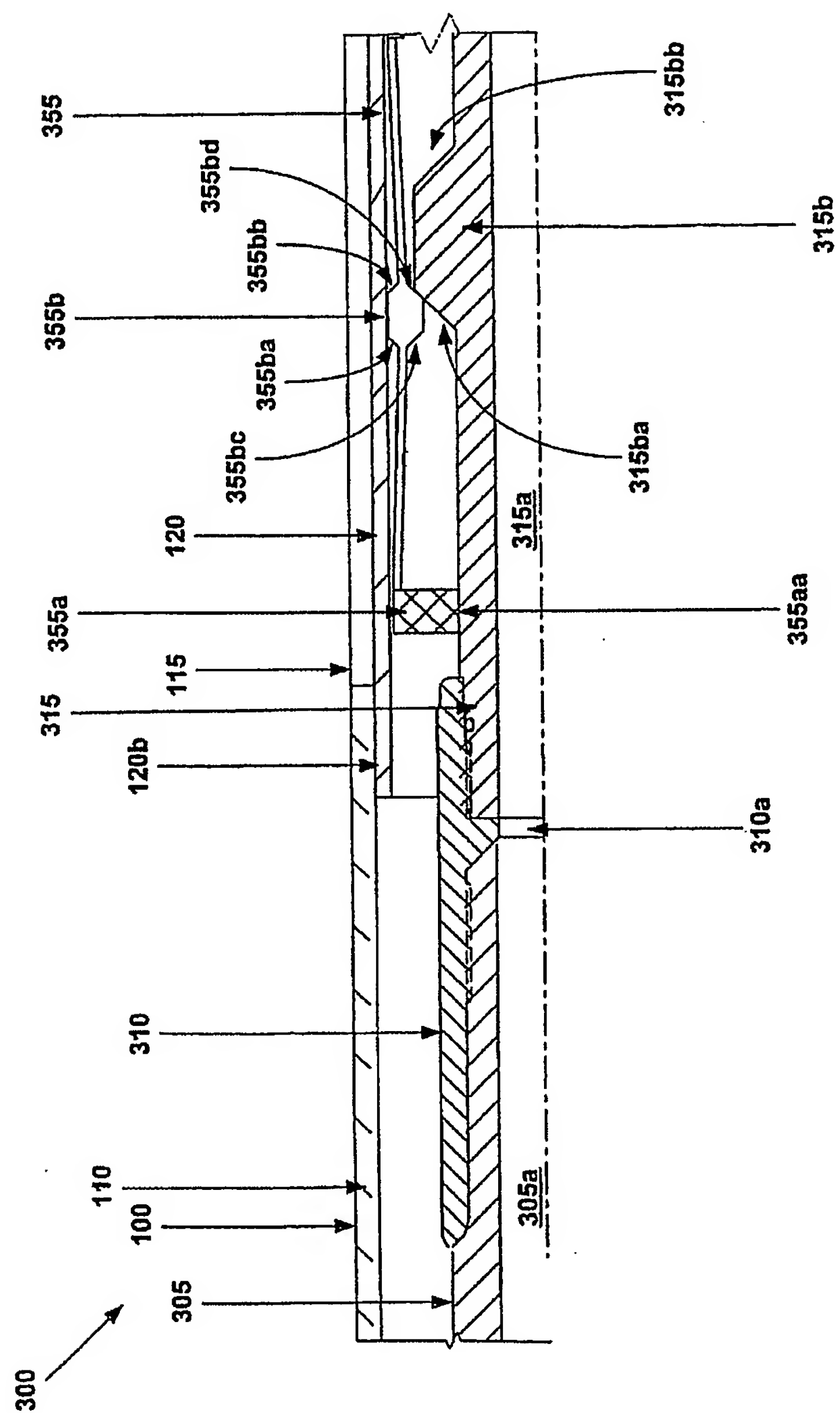


Fig. 3j





**Fig. 4**



**Fig. 4a**

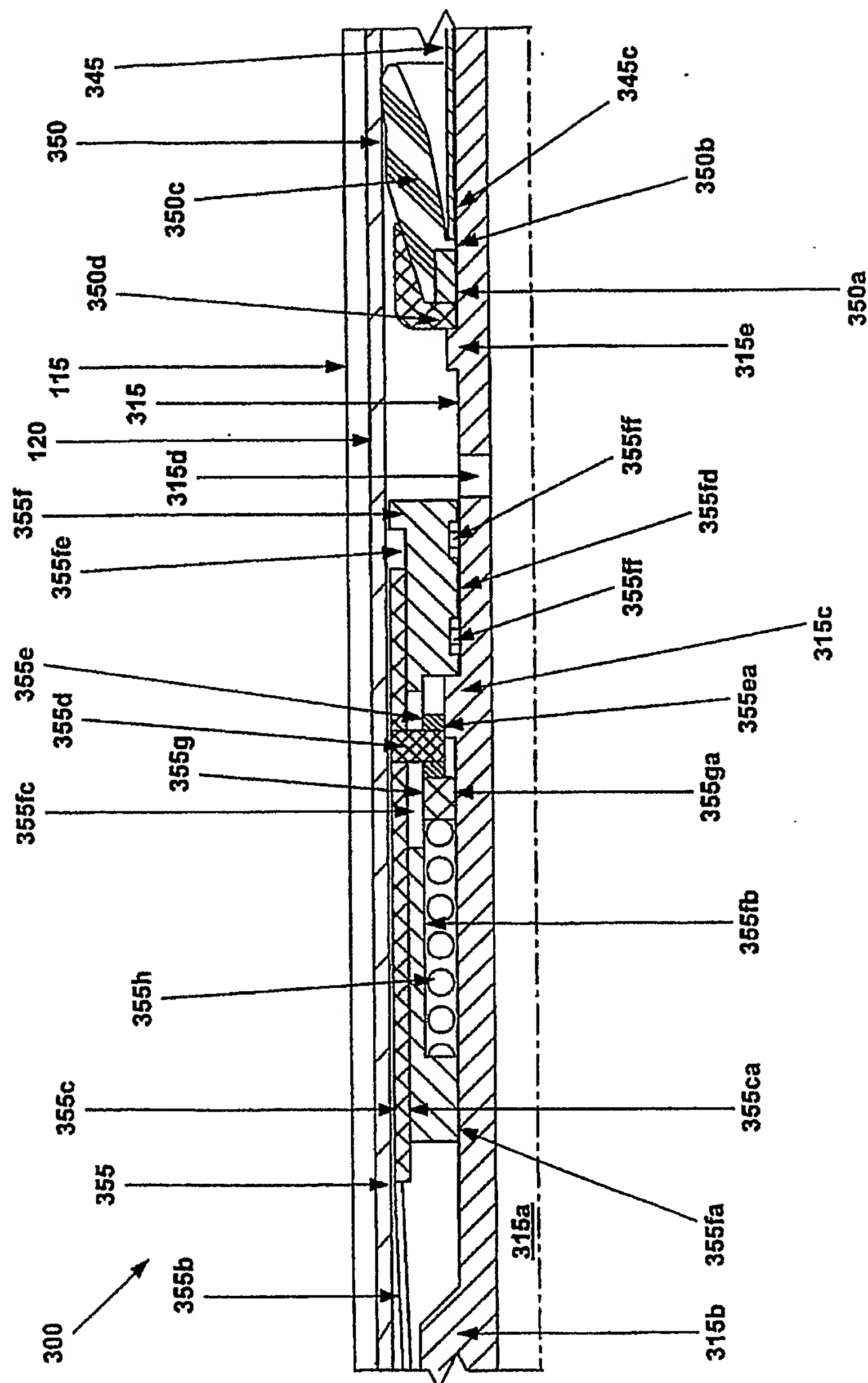


Fig. 4b

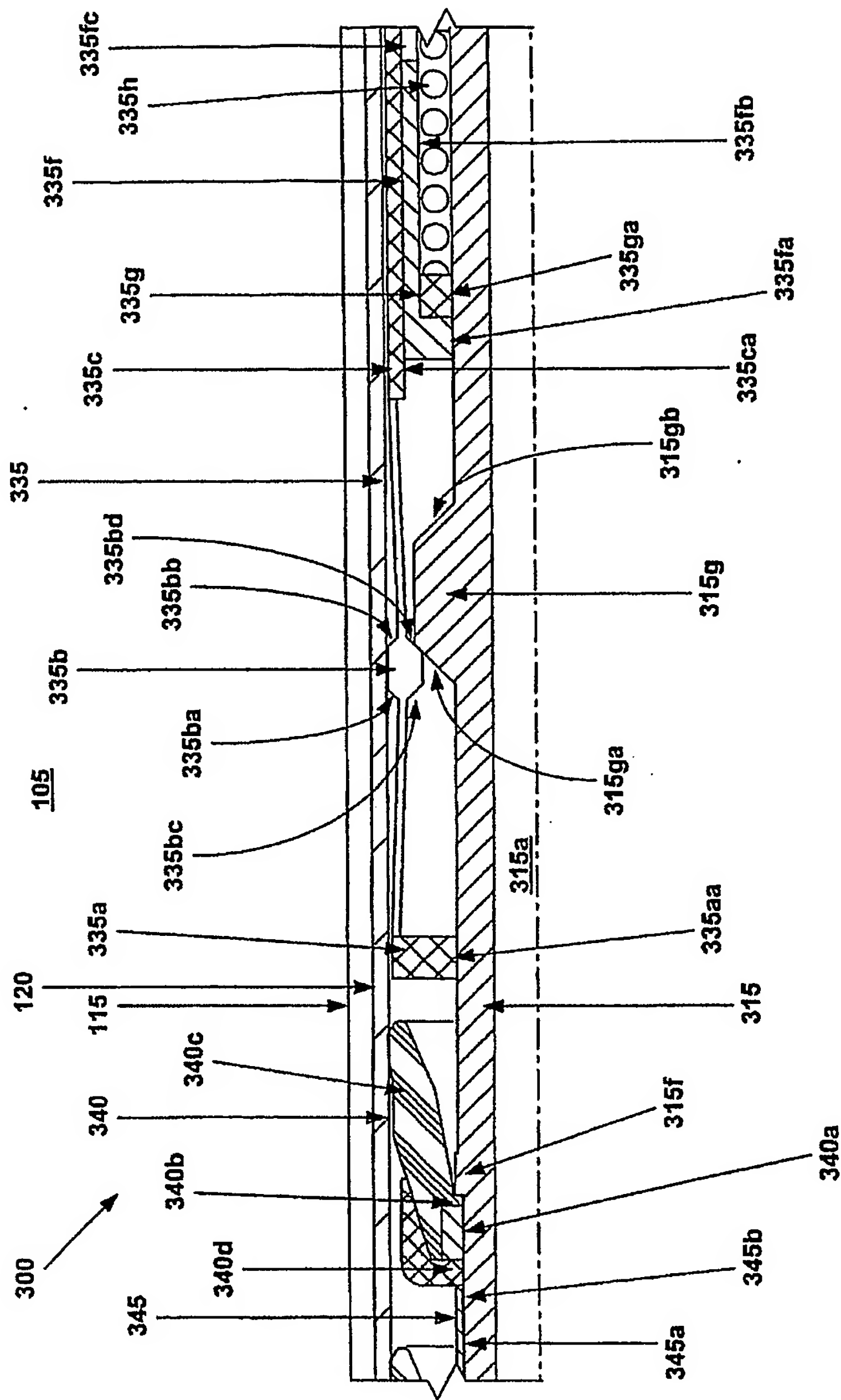


Fig. 4c

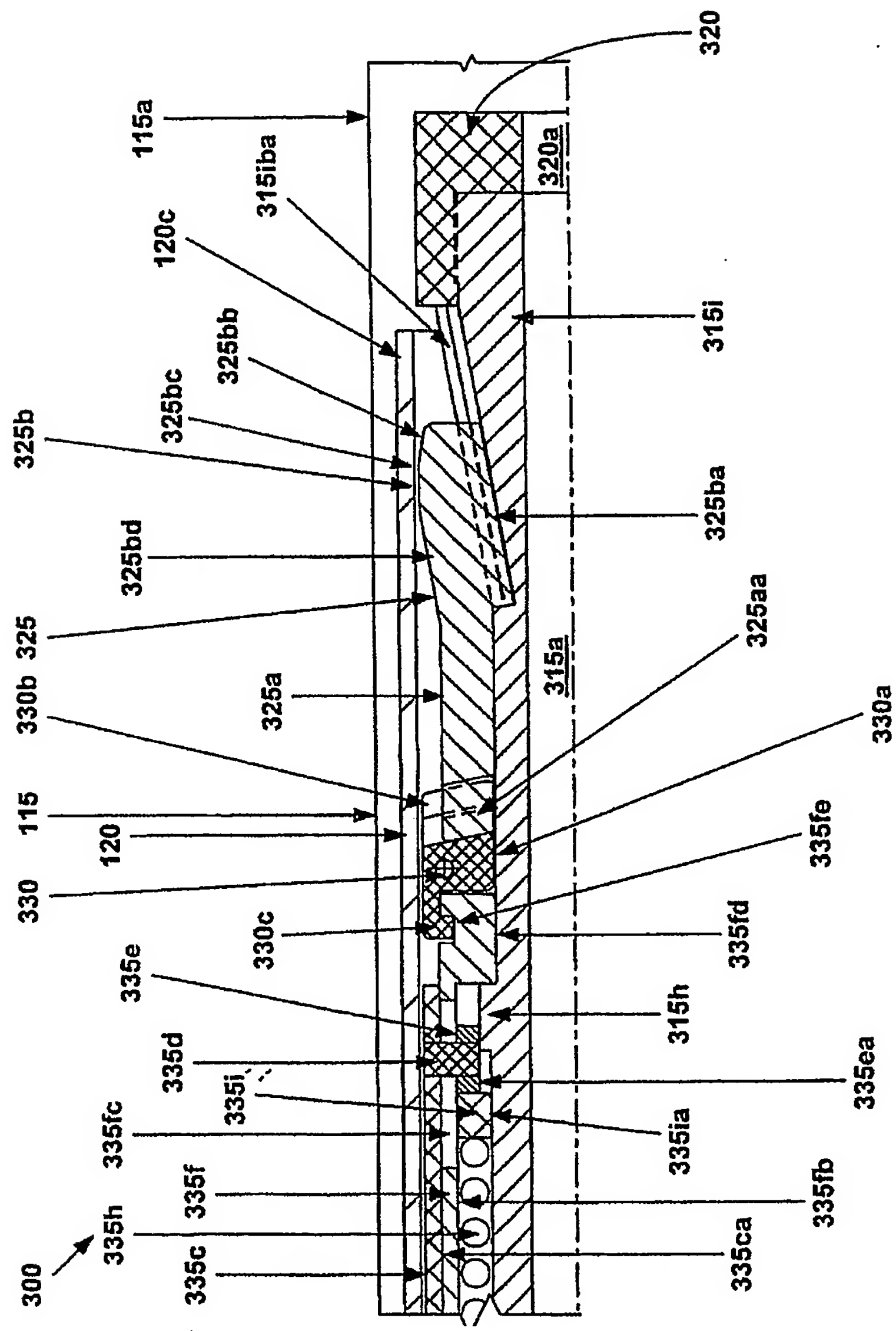


Fig. 4d



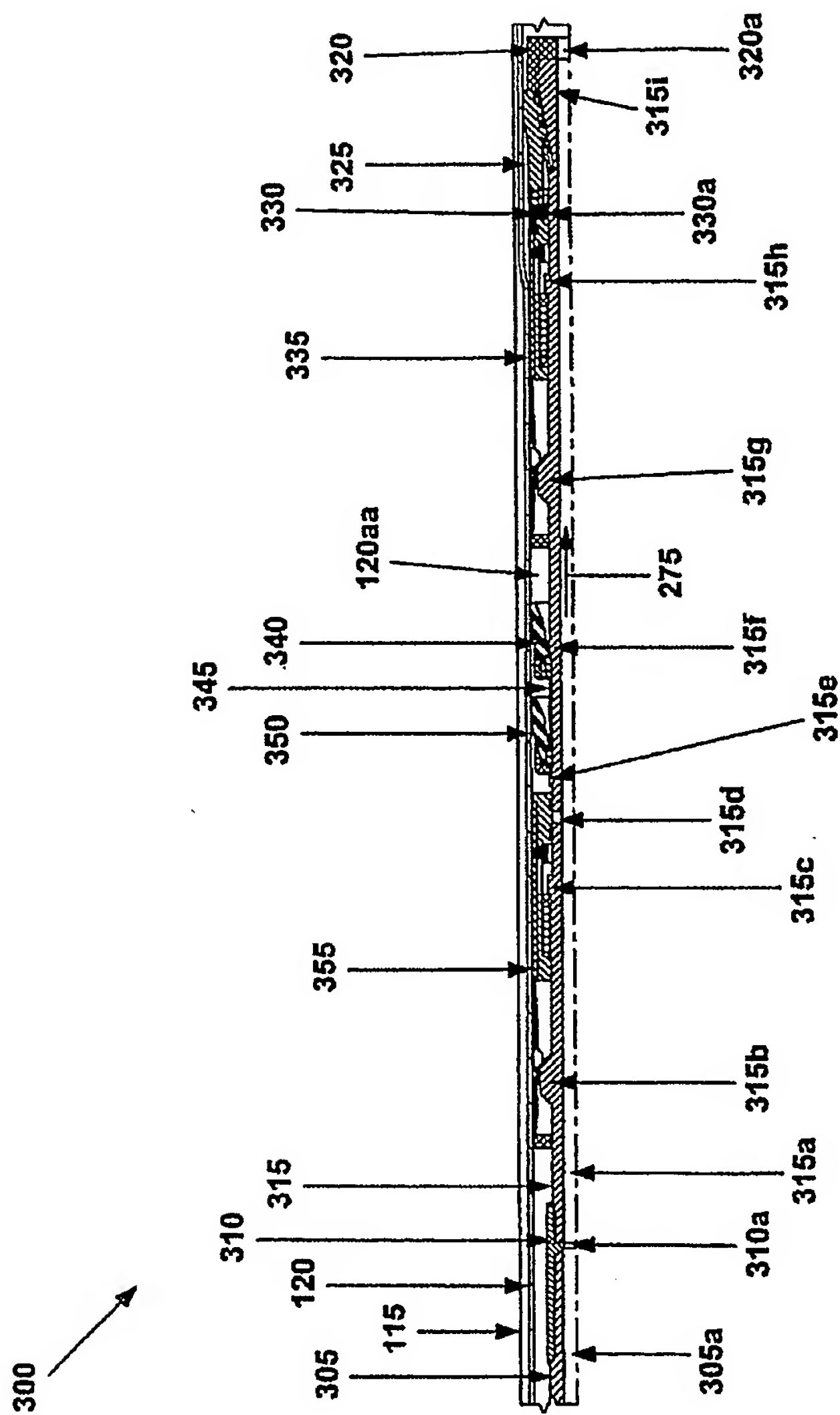


Fig. 5

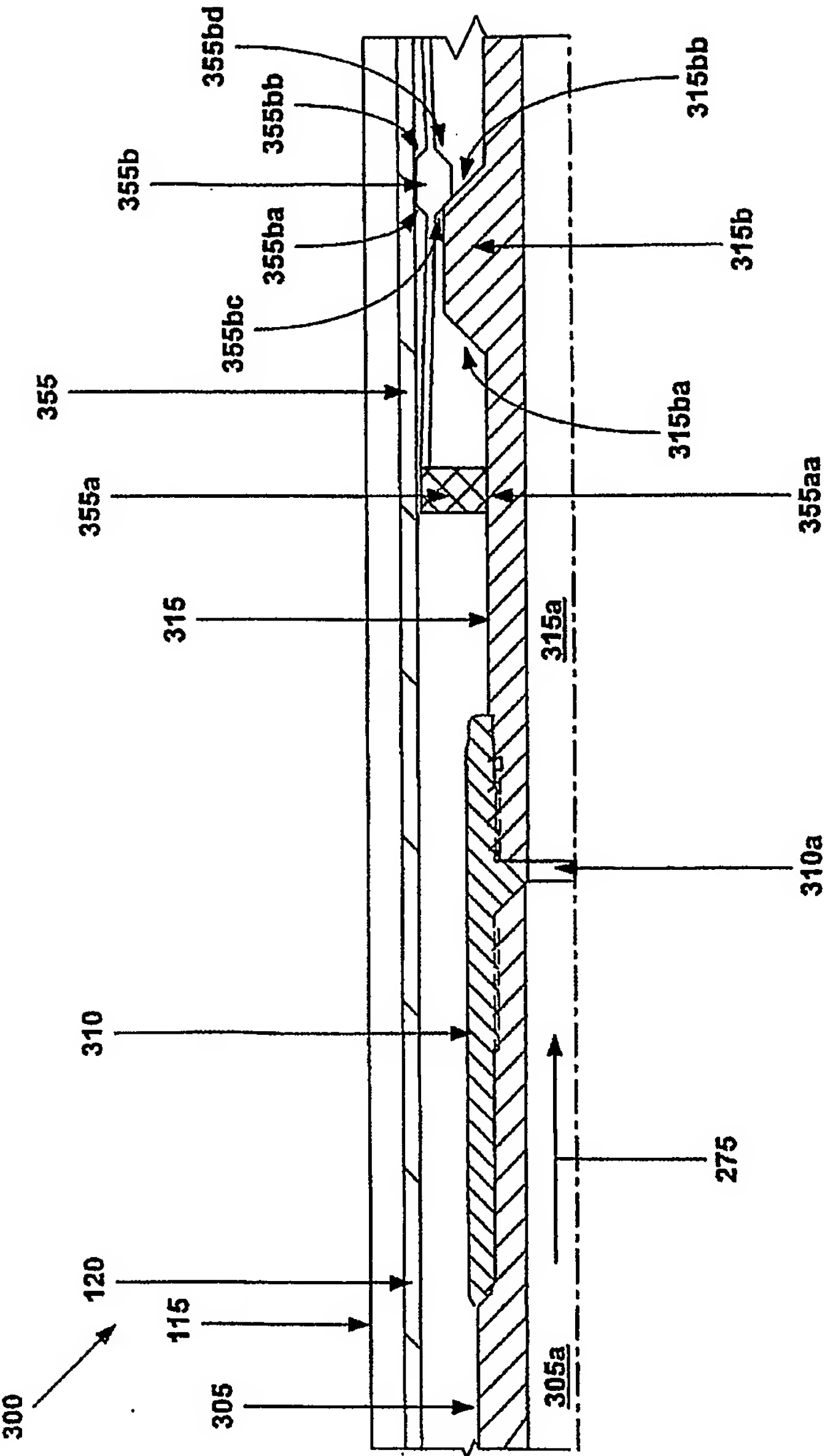


Fig. 5a

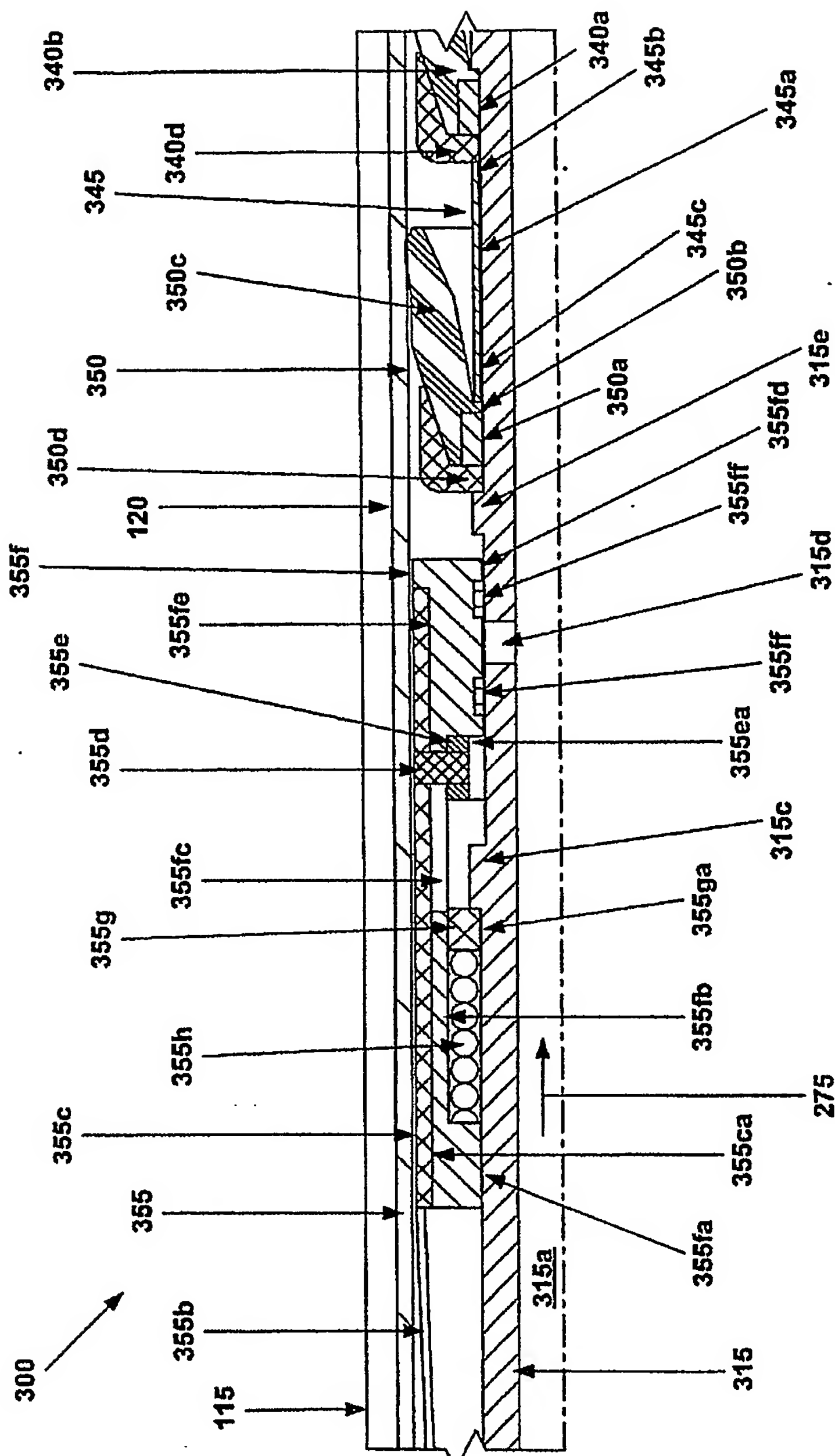
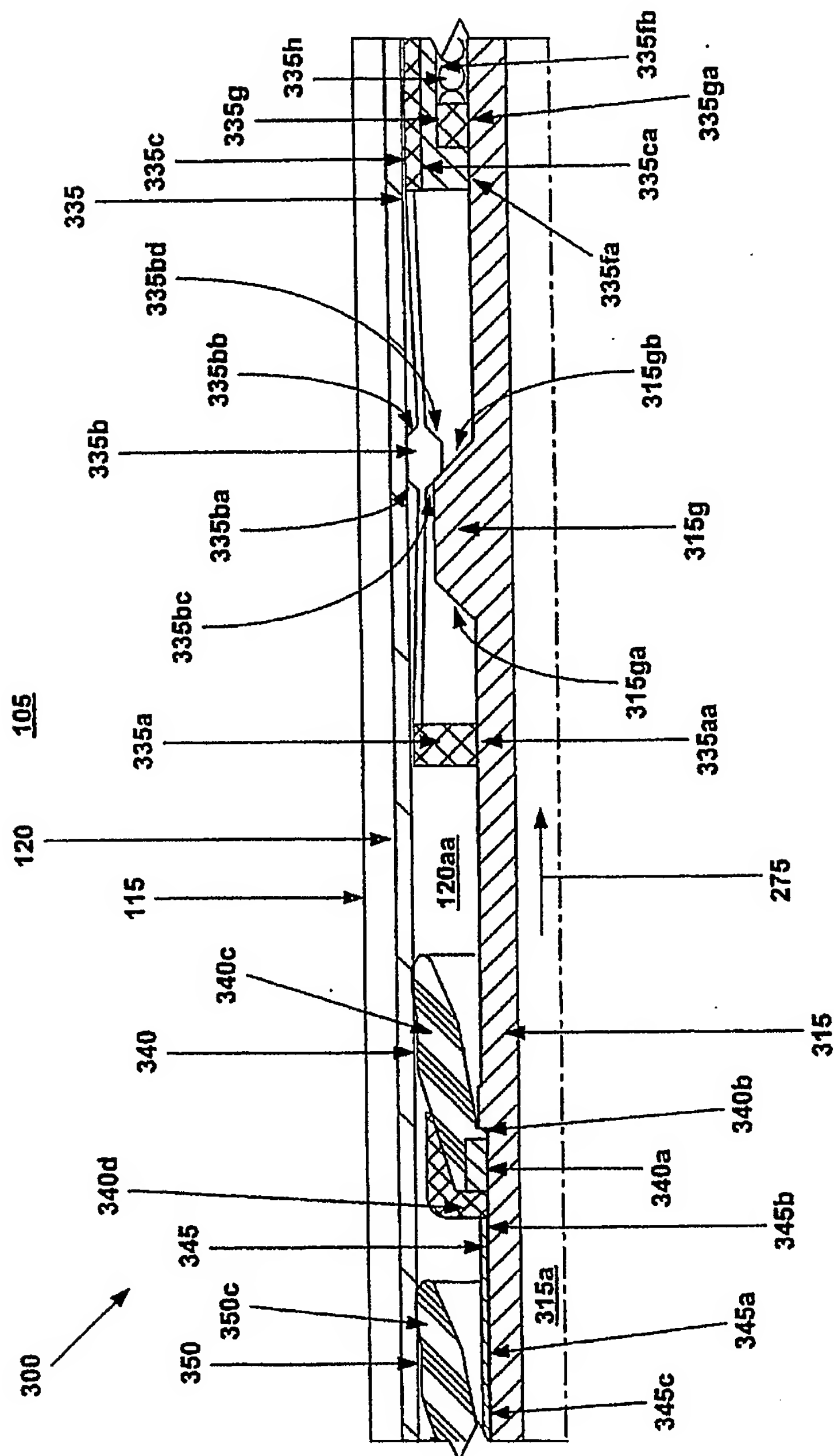


Fig. 5b



**Fig. 5c**

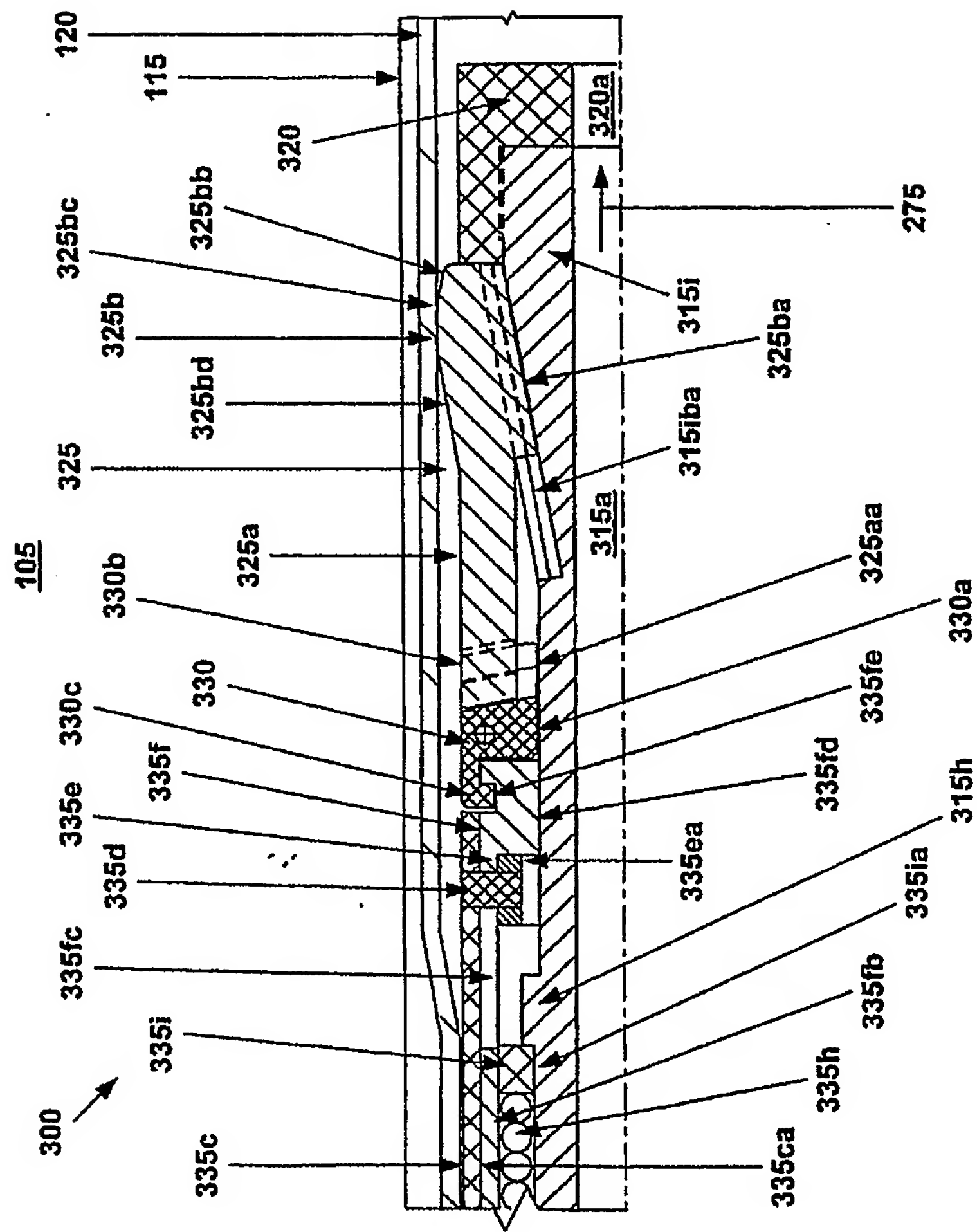


Fig. 5d



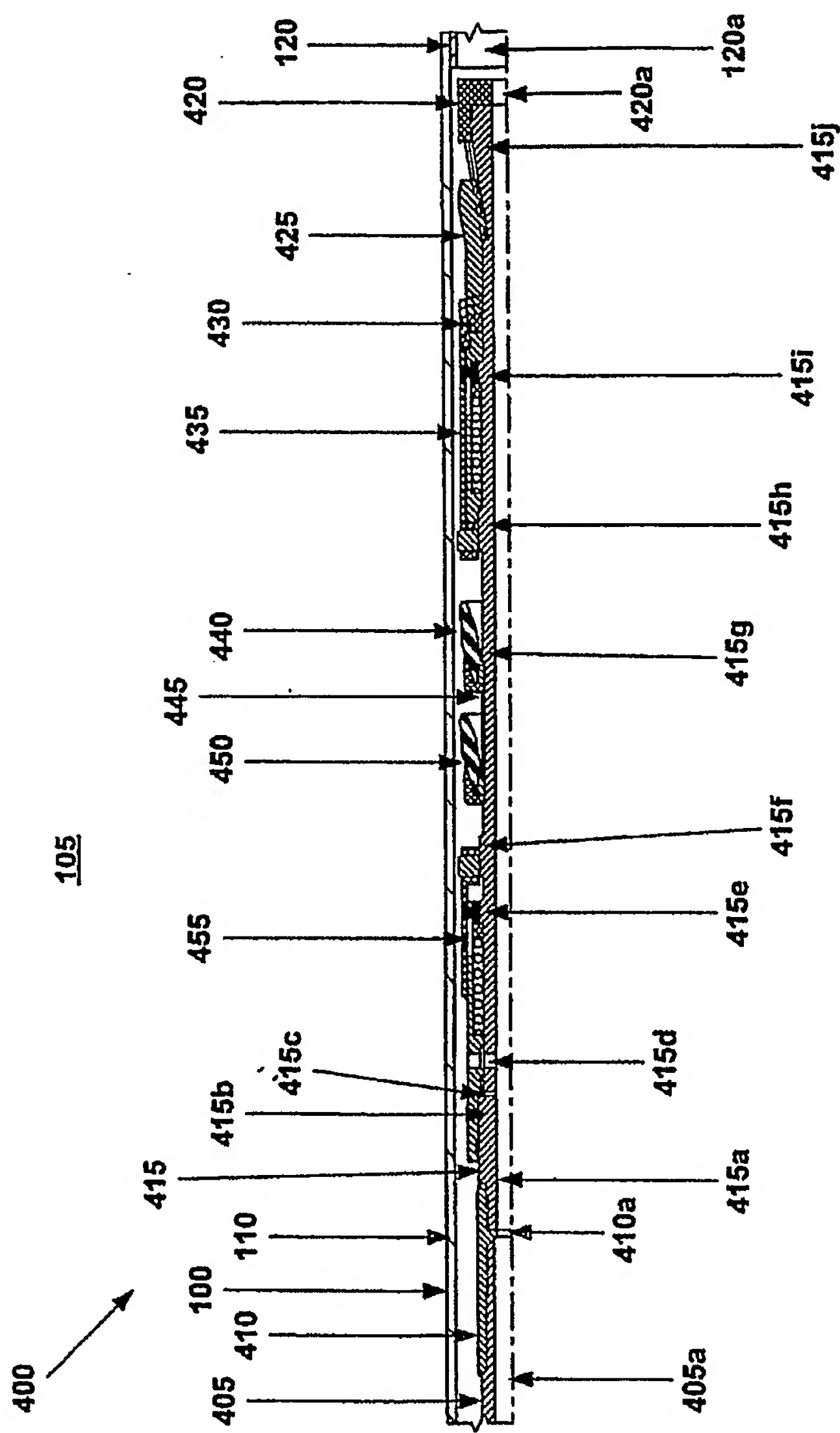
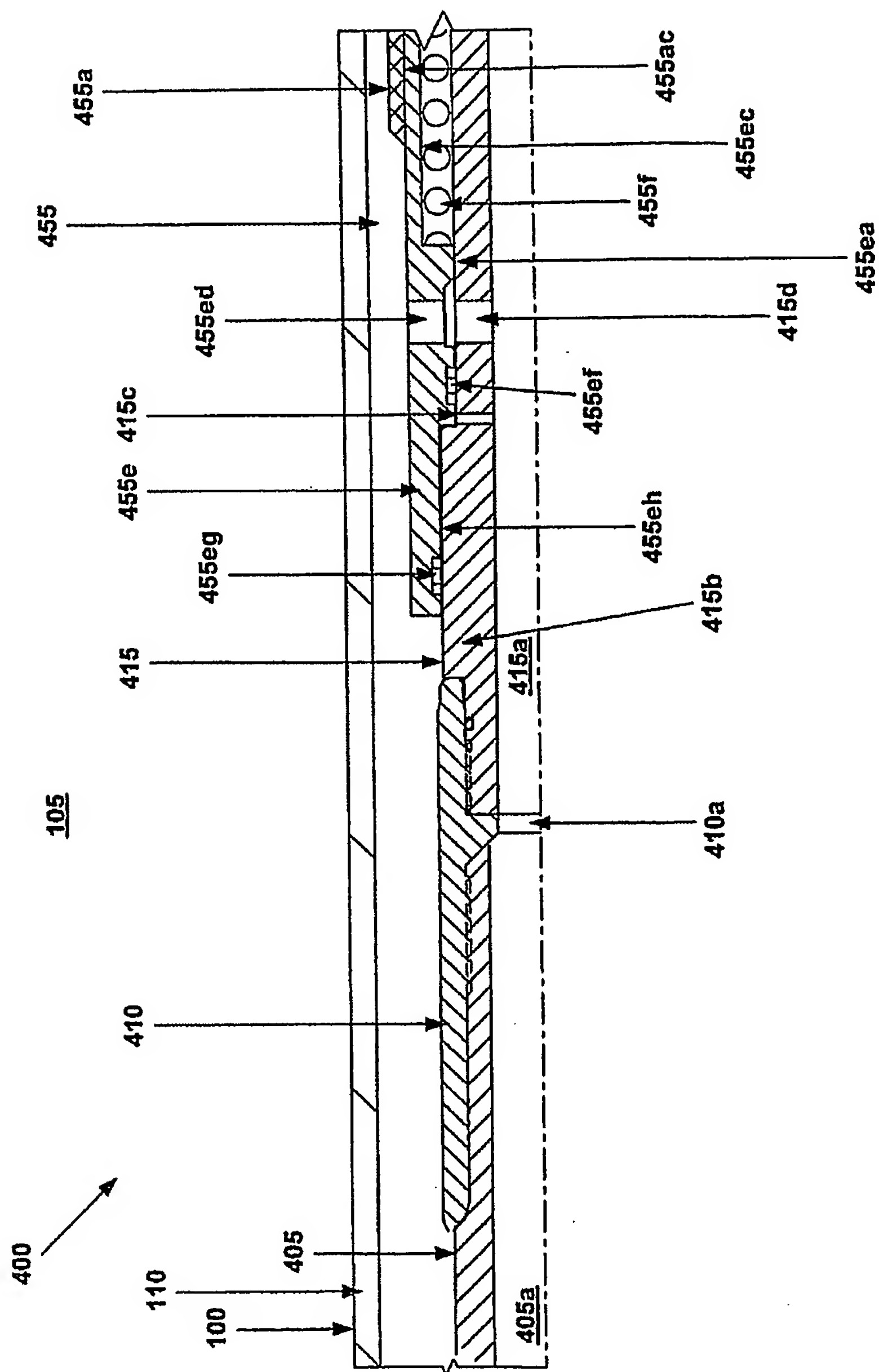


Fig. 6



**Fig. 6a**

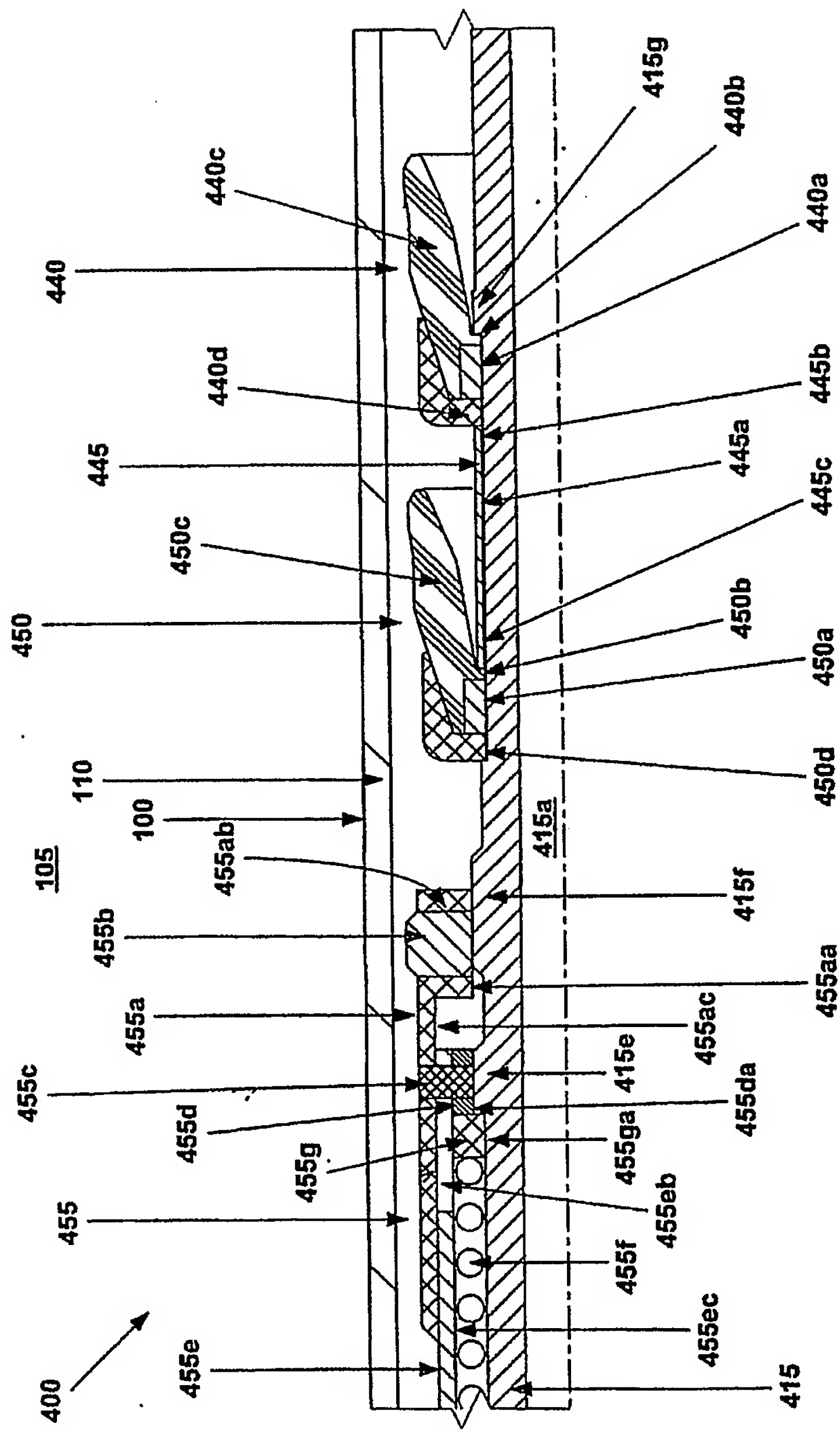


Fig. 6b

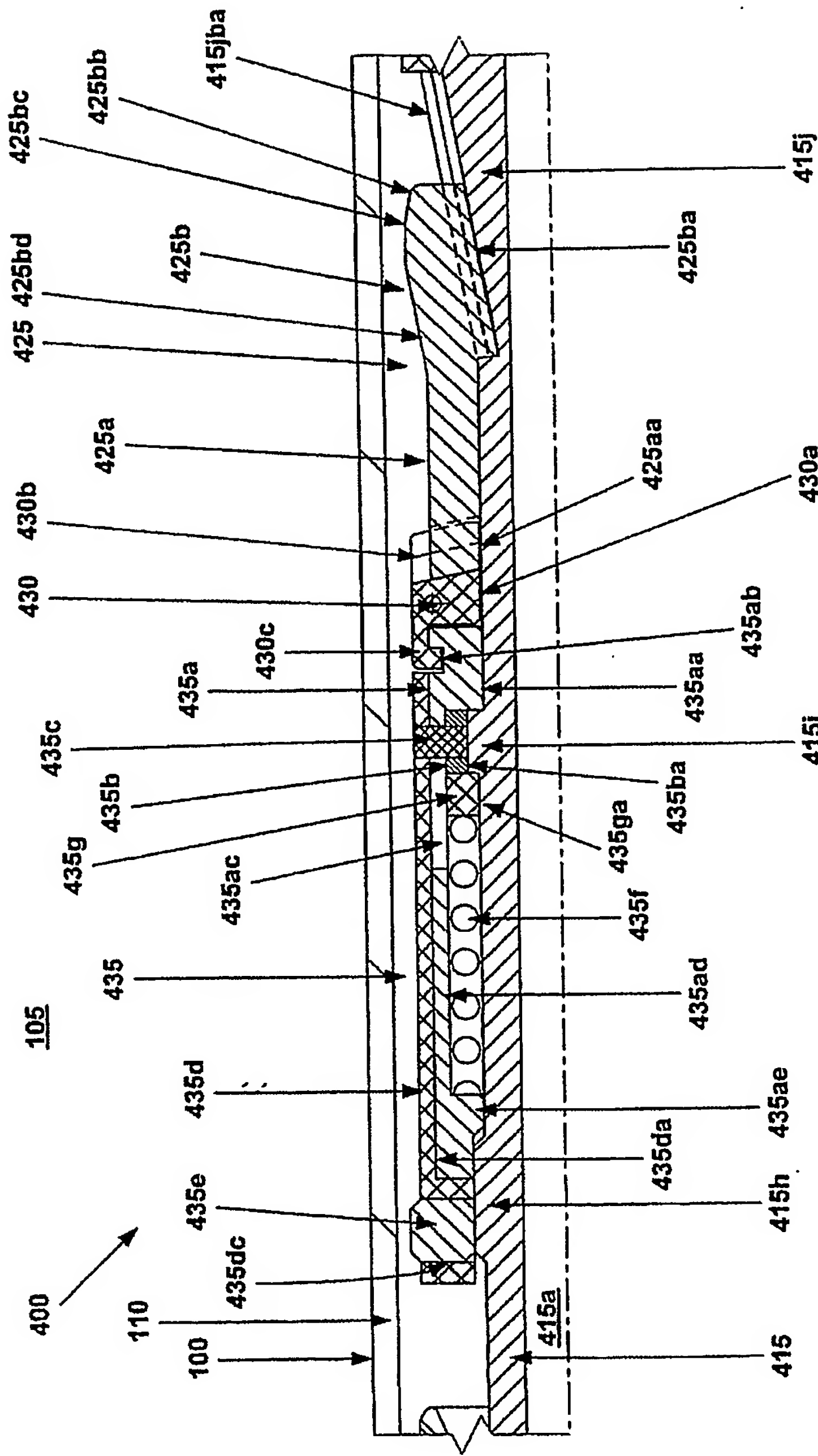


Fig. 6c

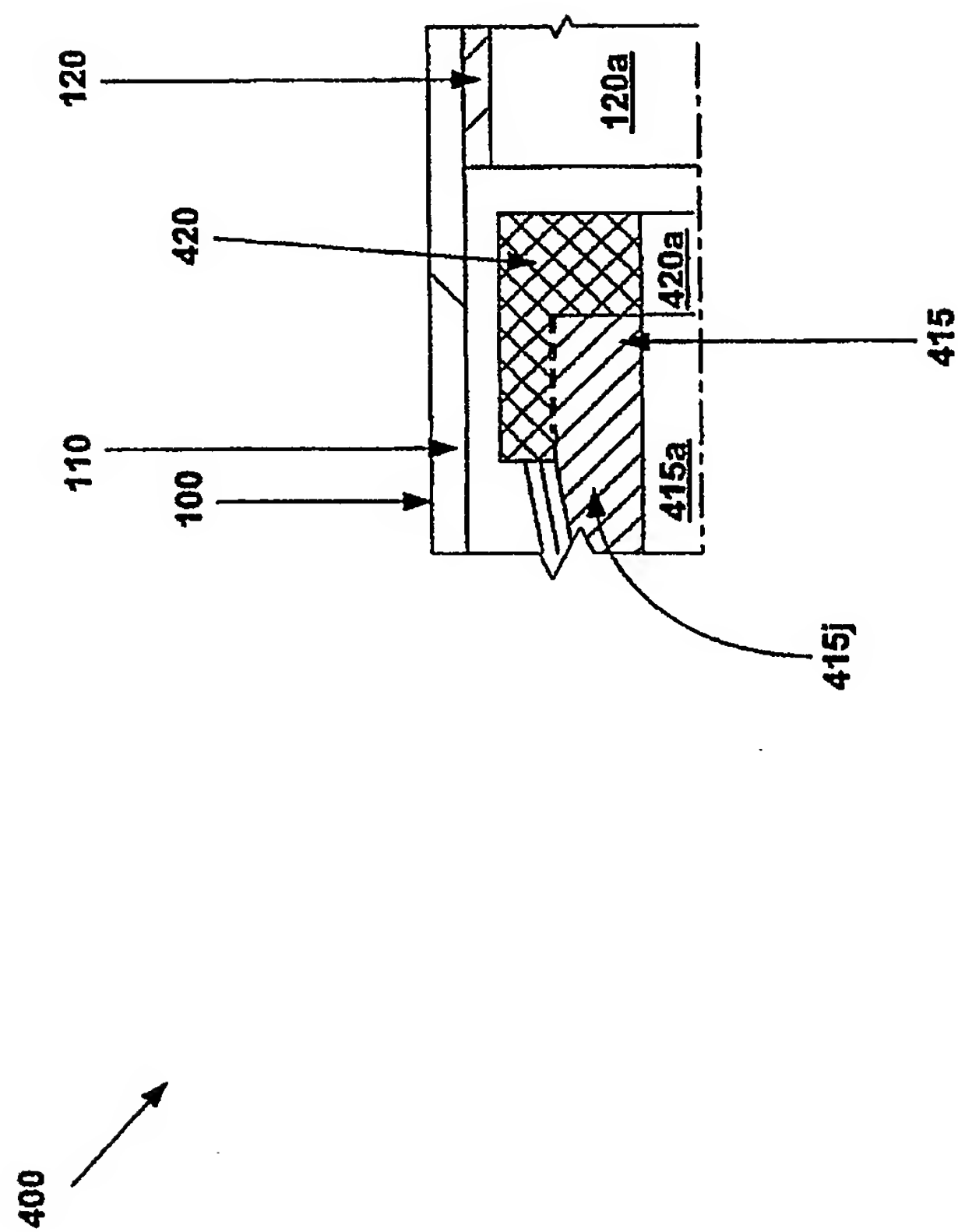
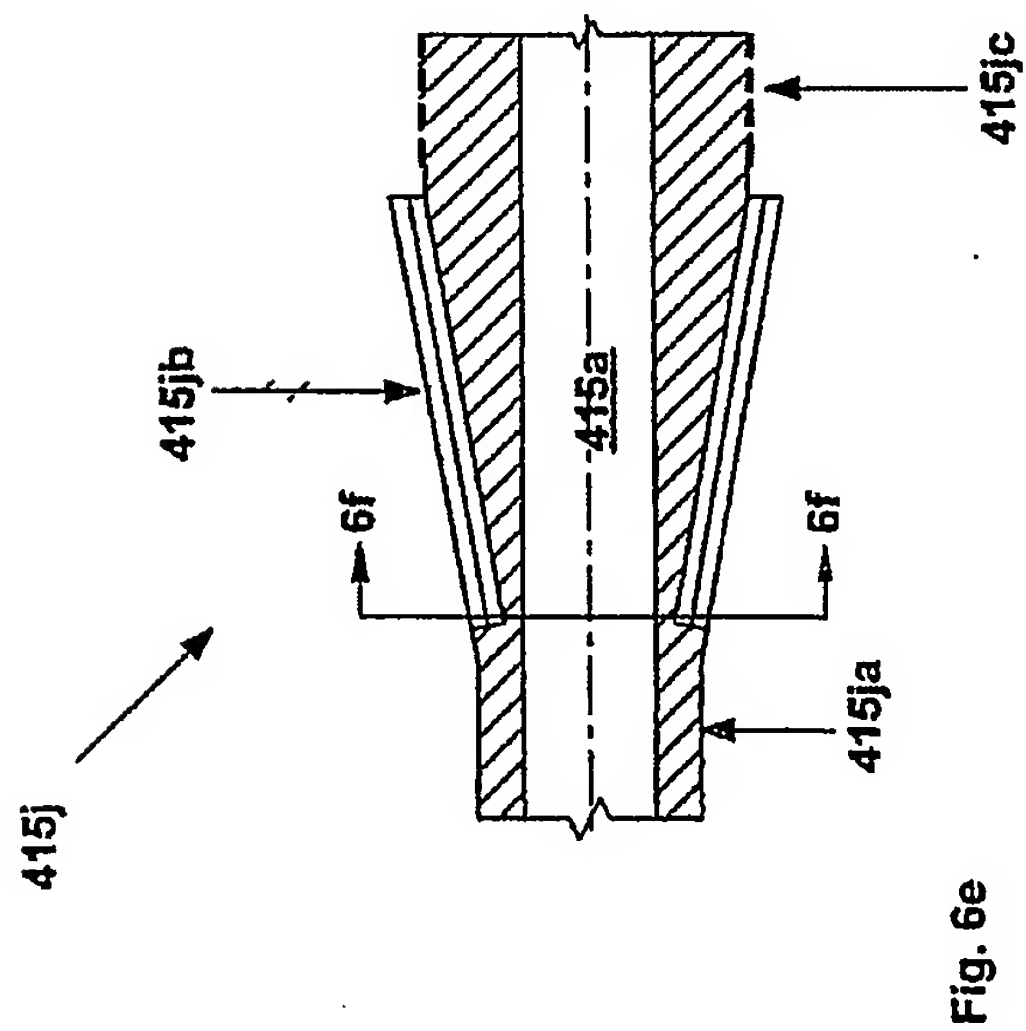
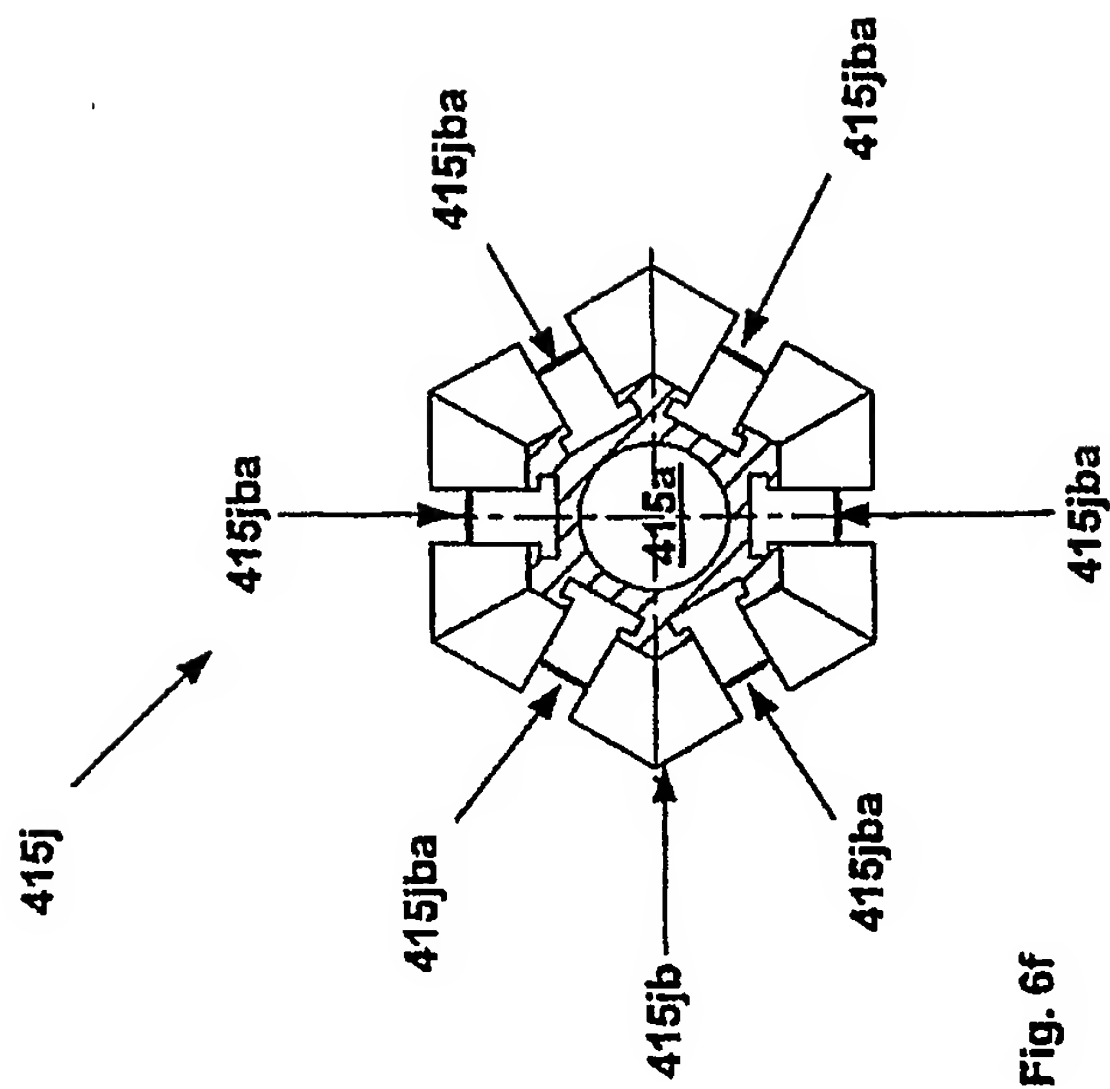


Fig. 6d





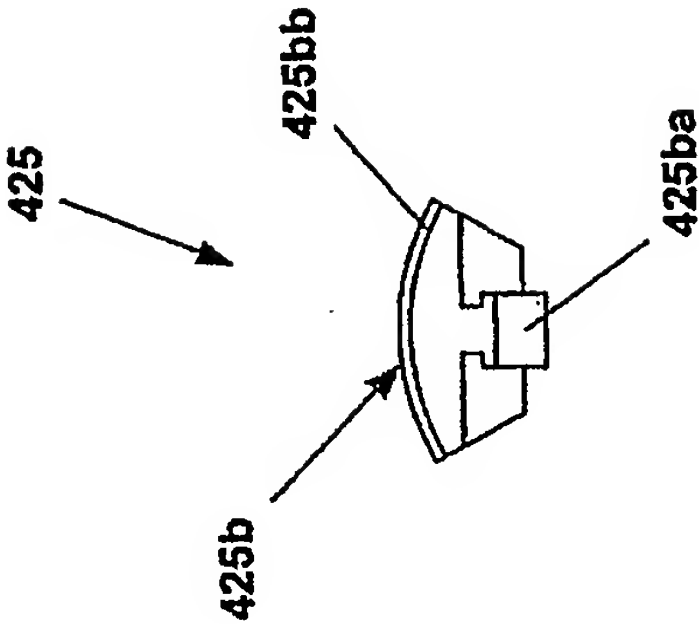


Fig. 6h

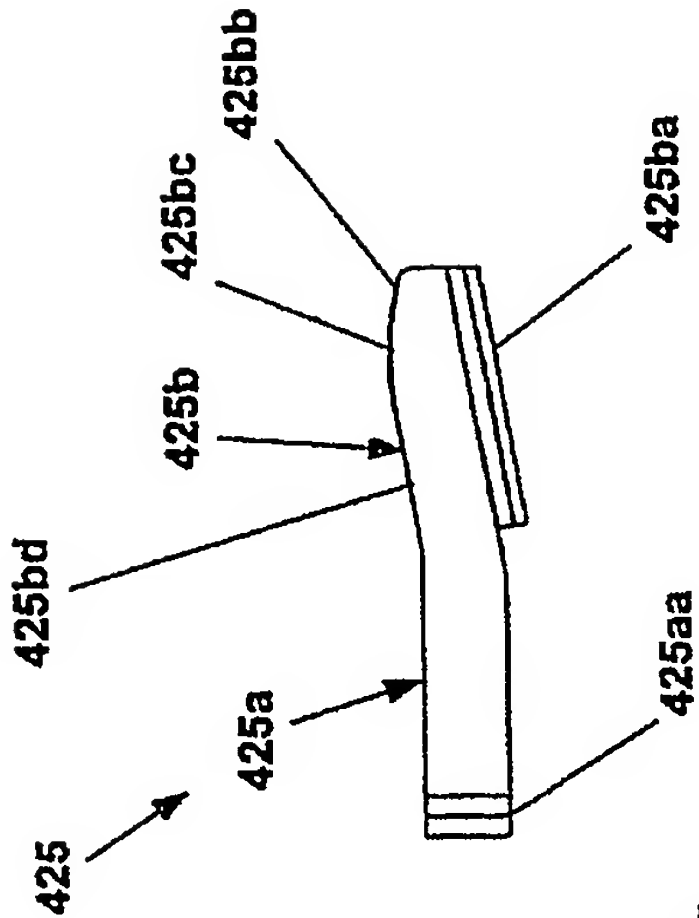


Fig. 6g

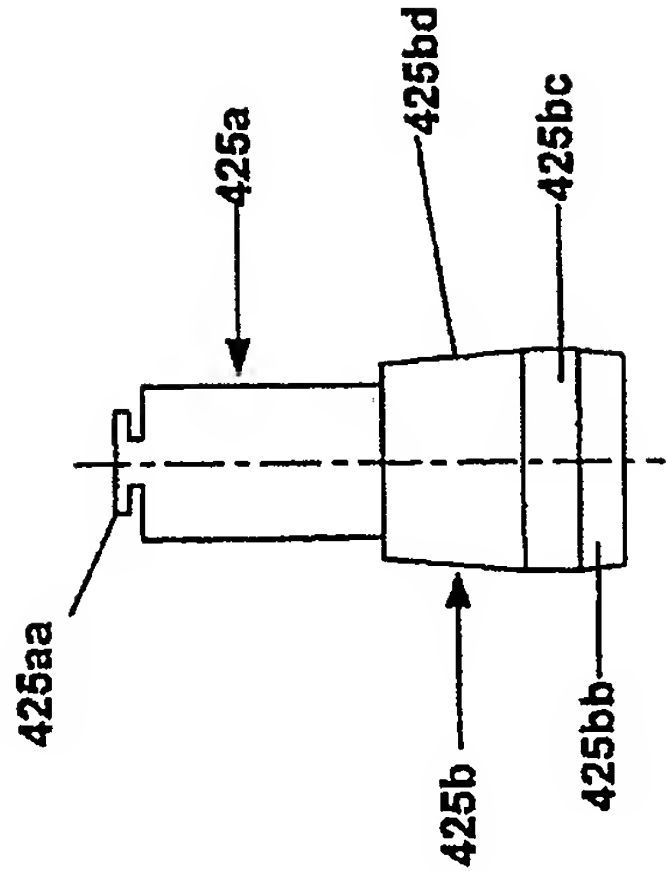


Fig. 6i

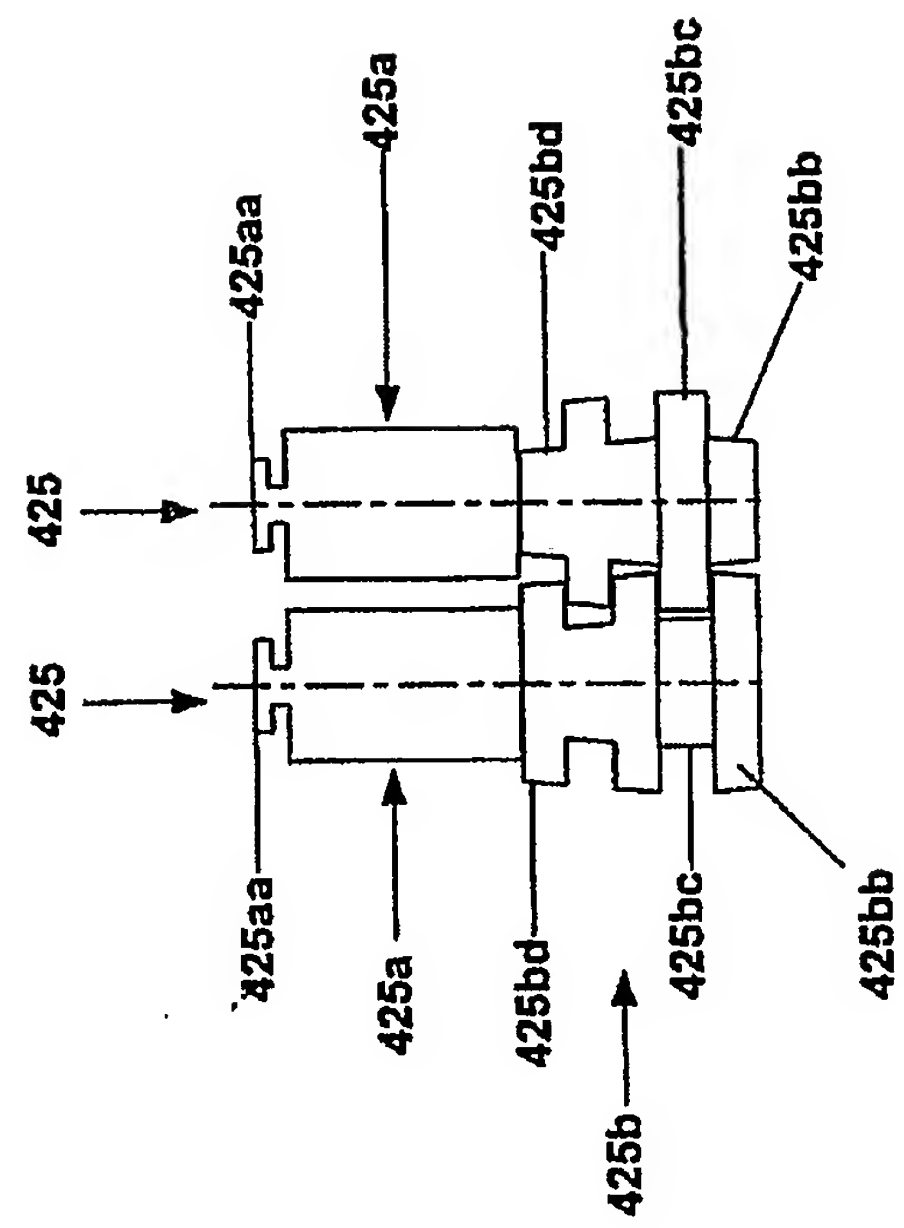


Fig. 6j

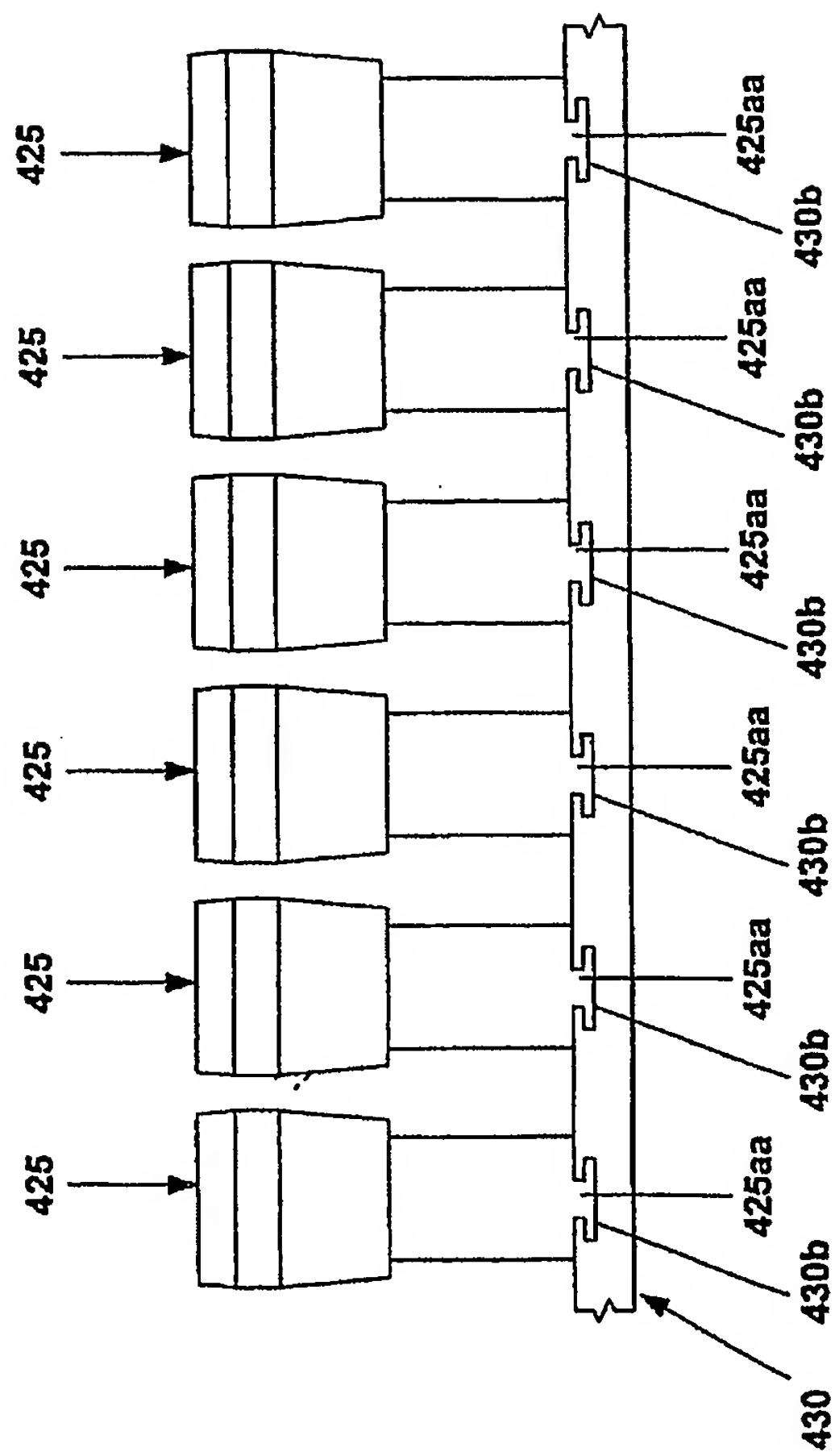


Fig. 6k

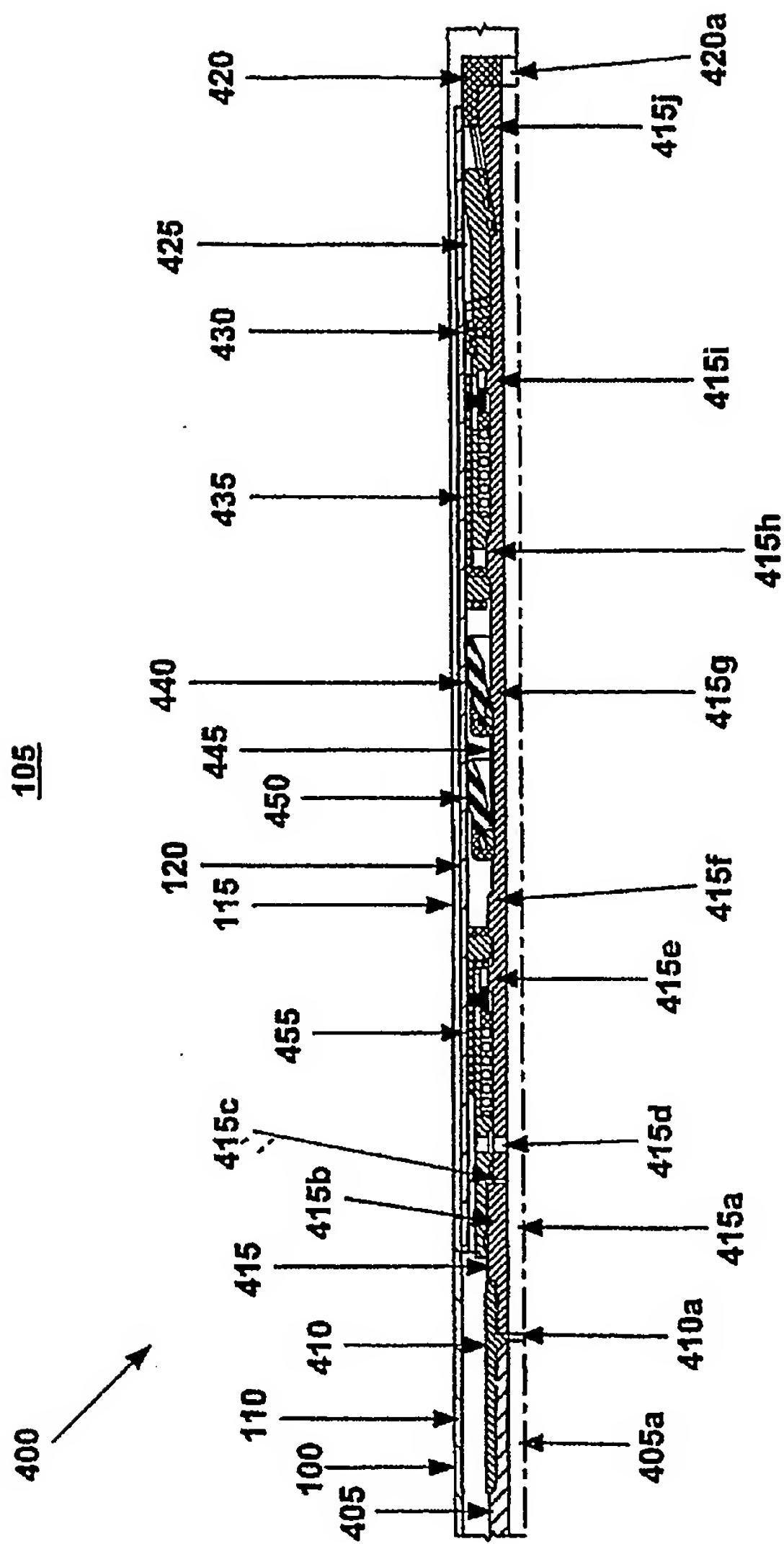


Fig. 7



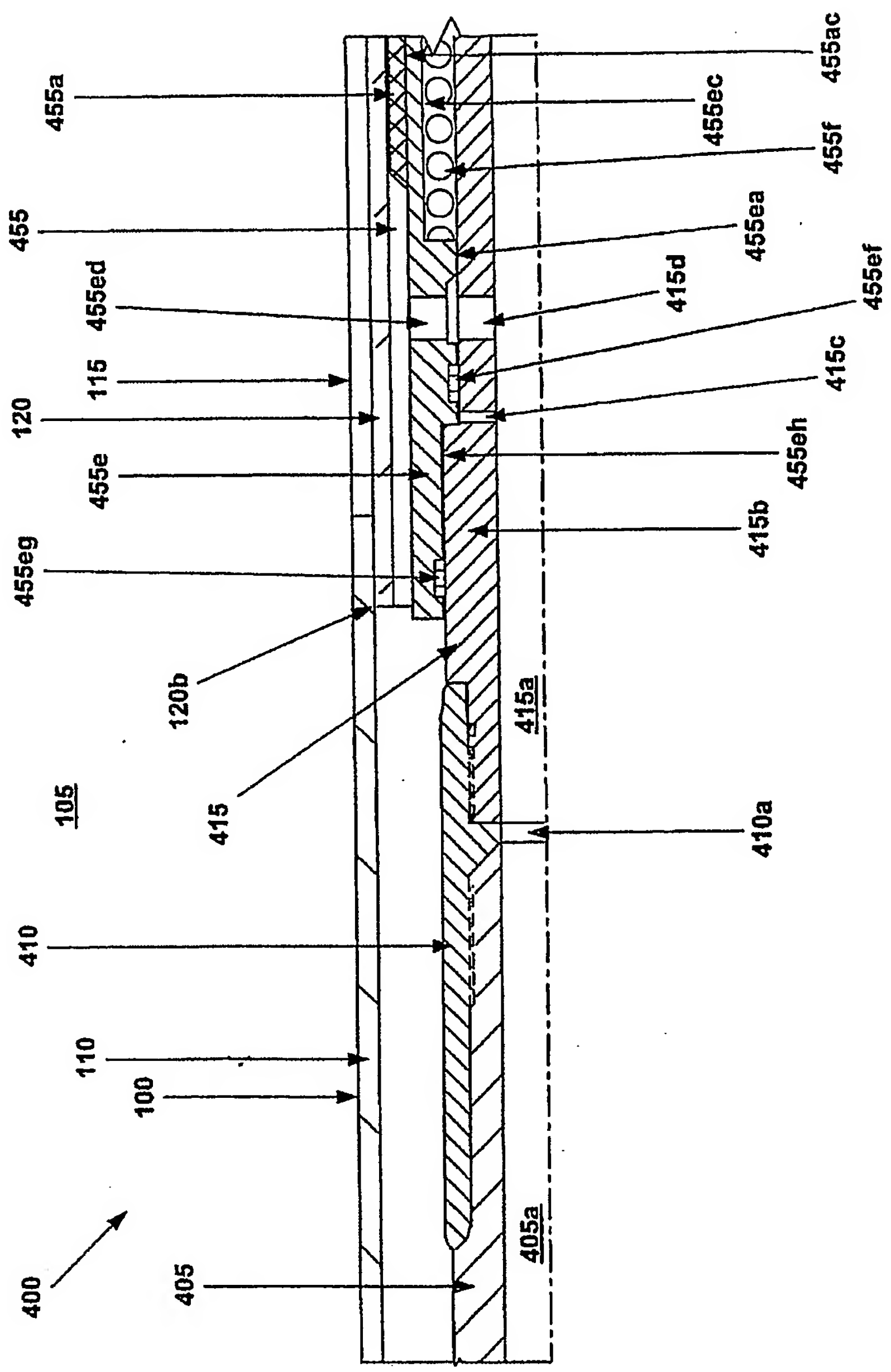


Fig. 7a

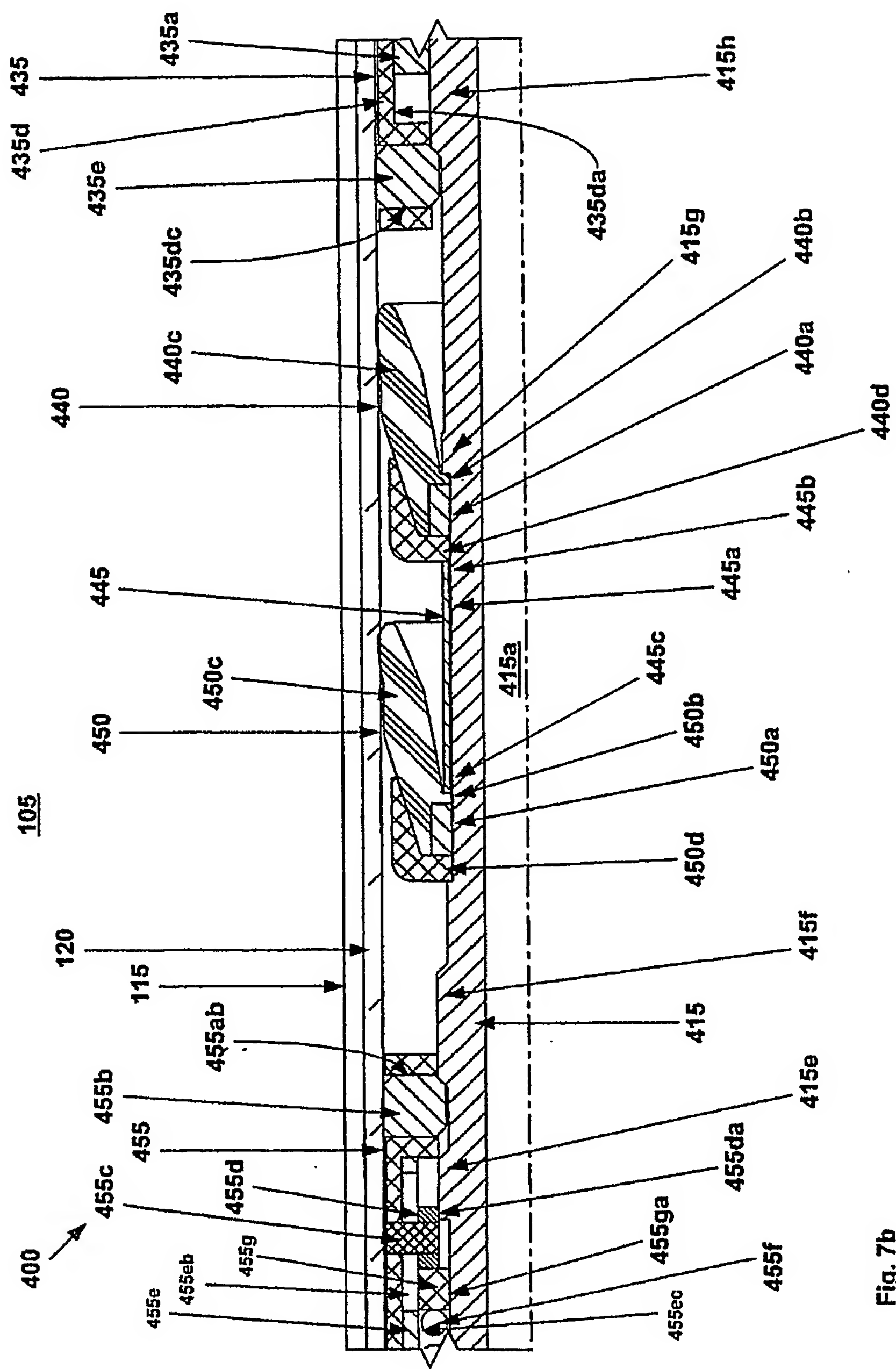


Fig. 7b

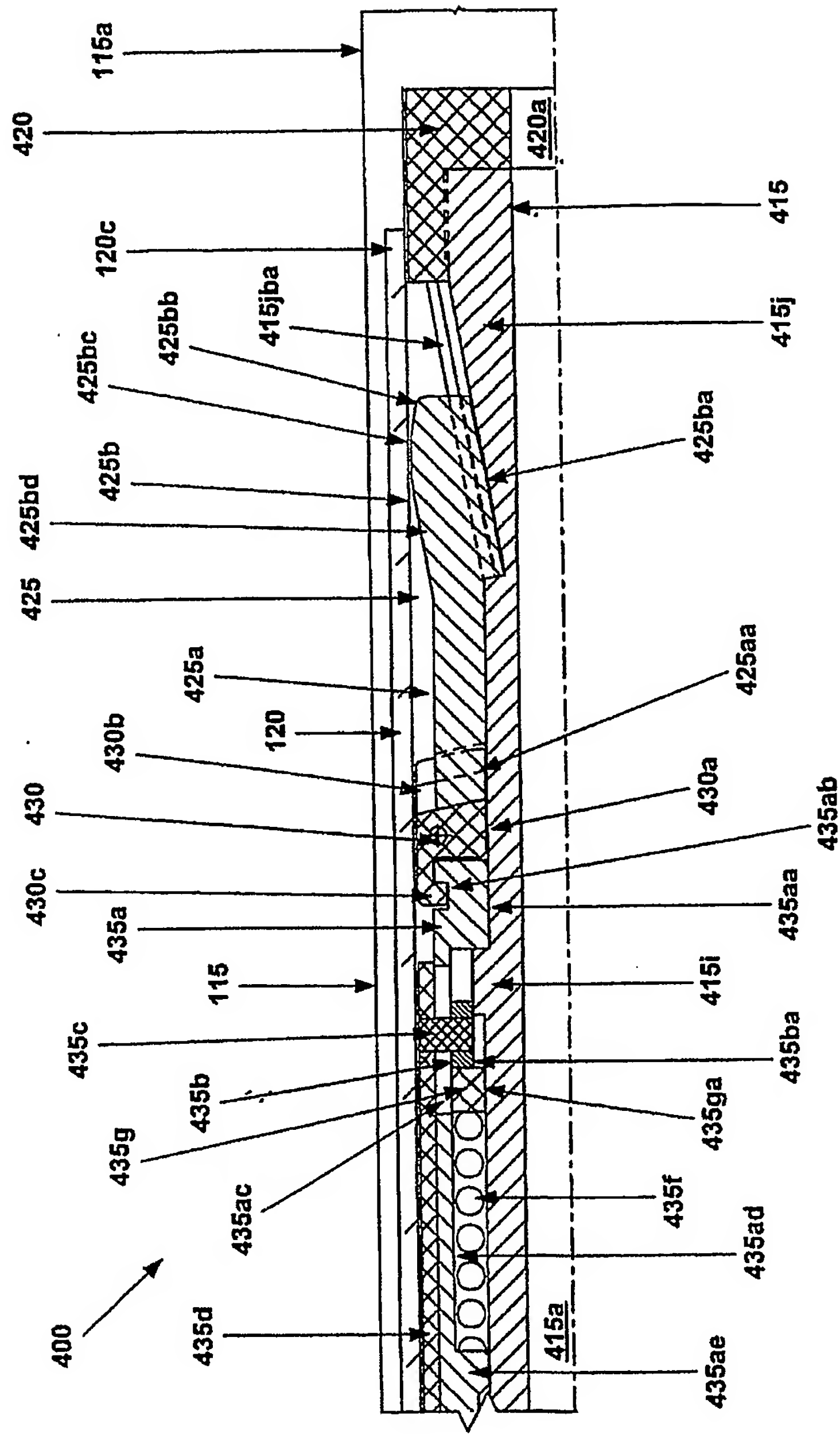


Fig. 7c

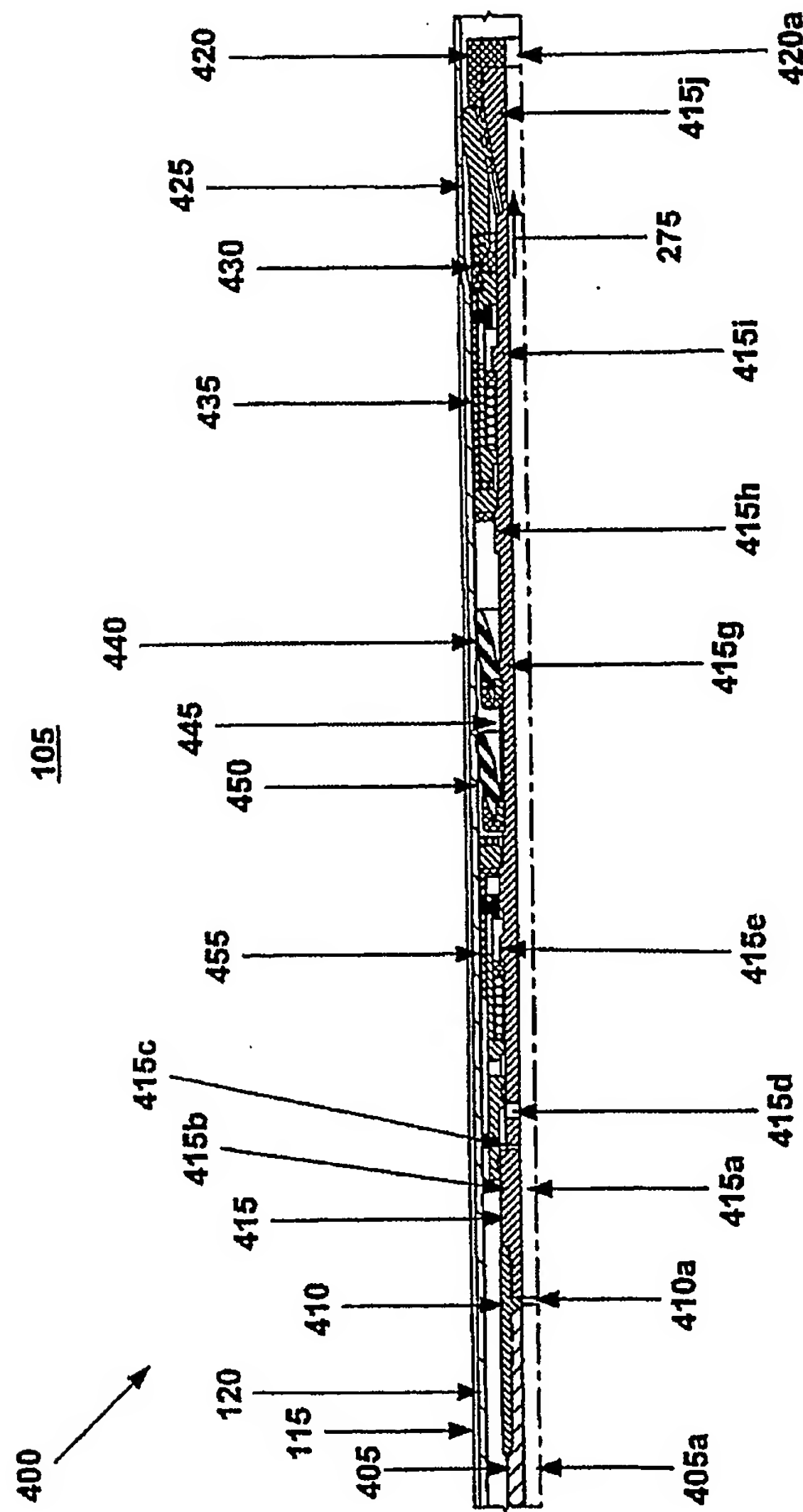


Fig. 8

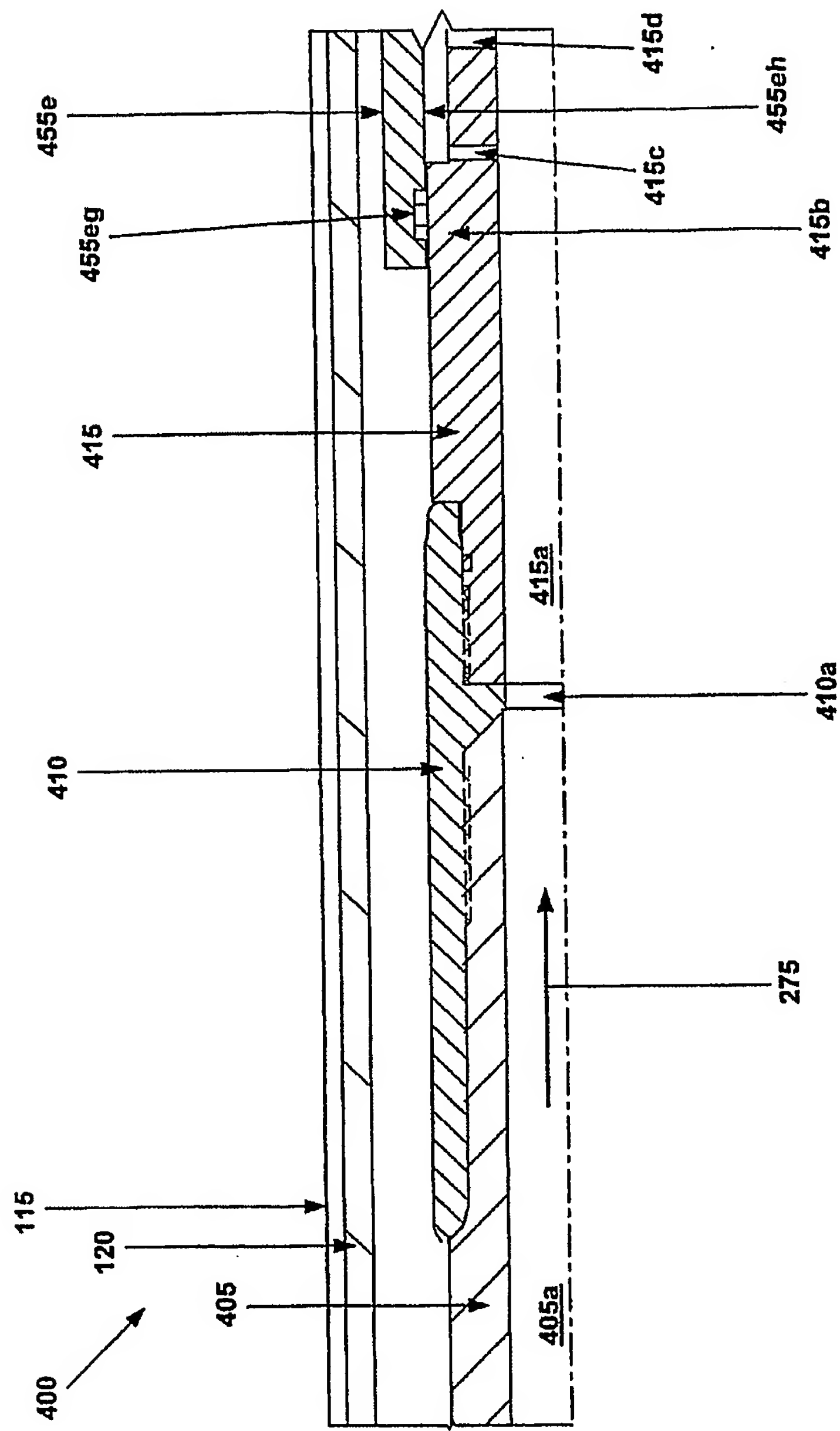


Fig. 8a



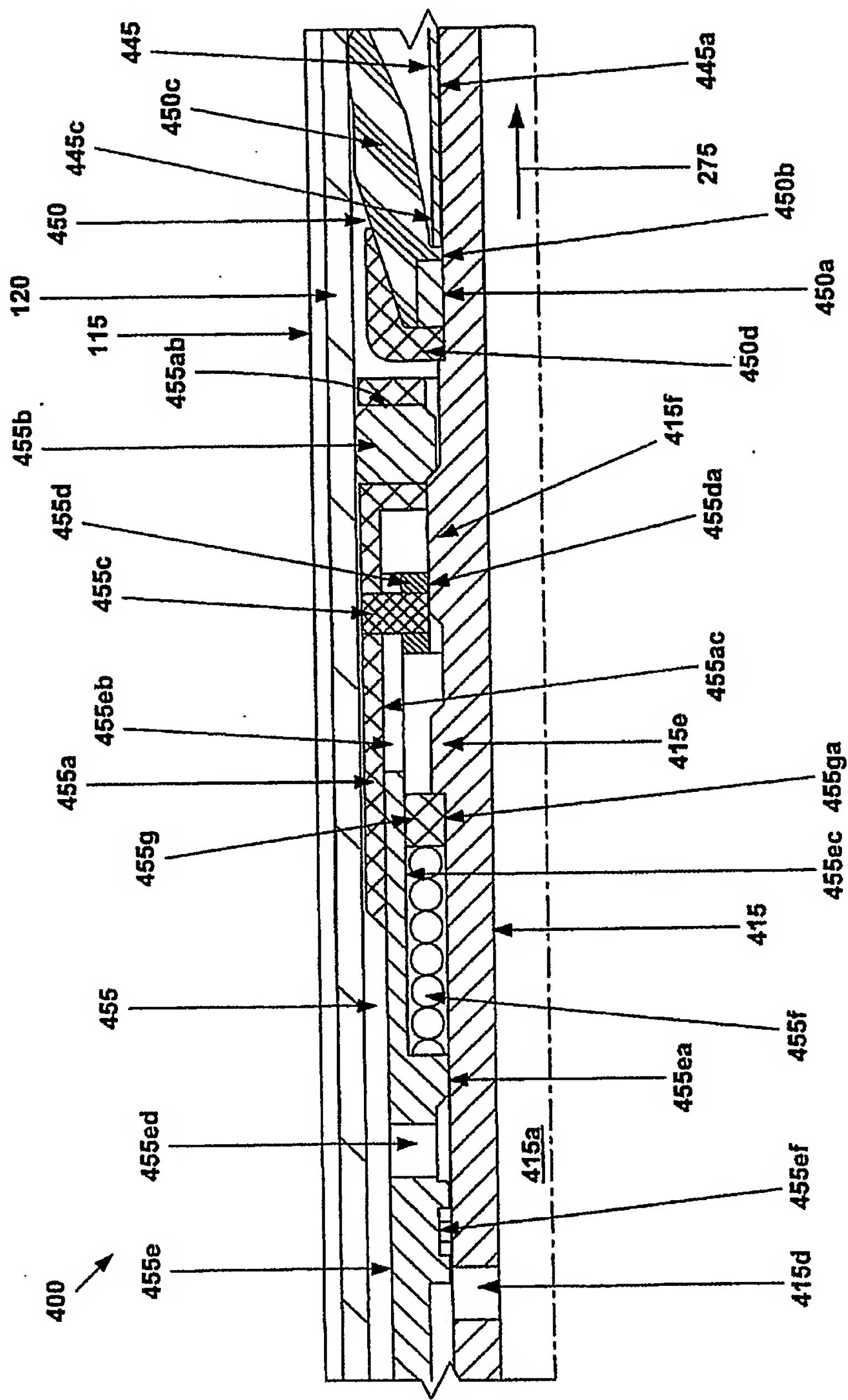


Fig. 8b

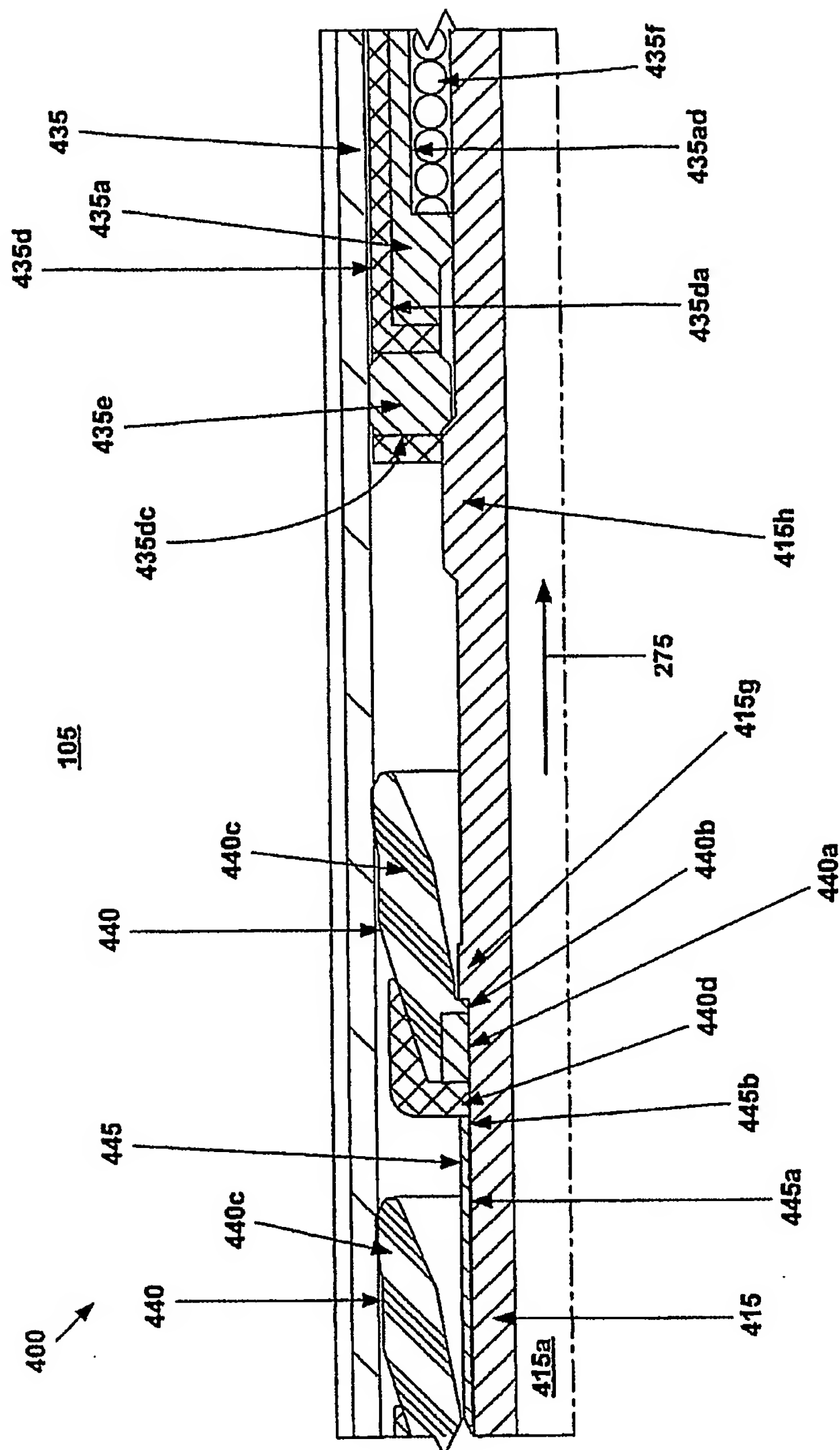
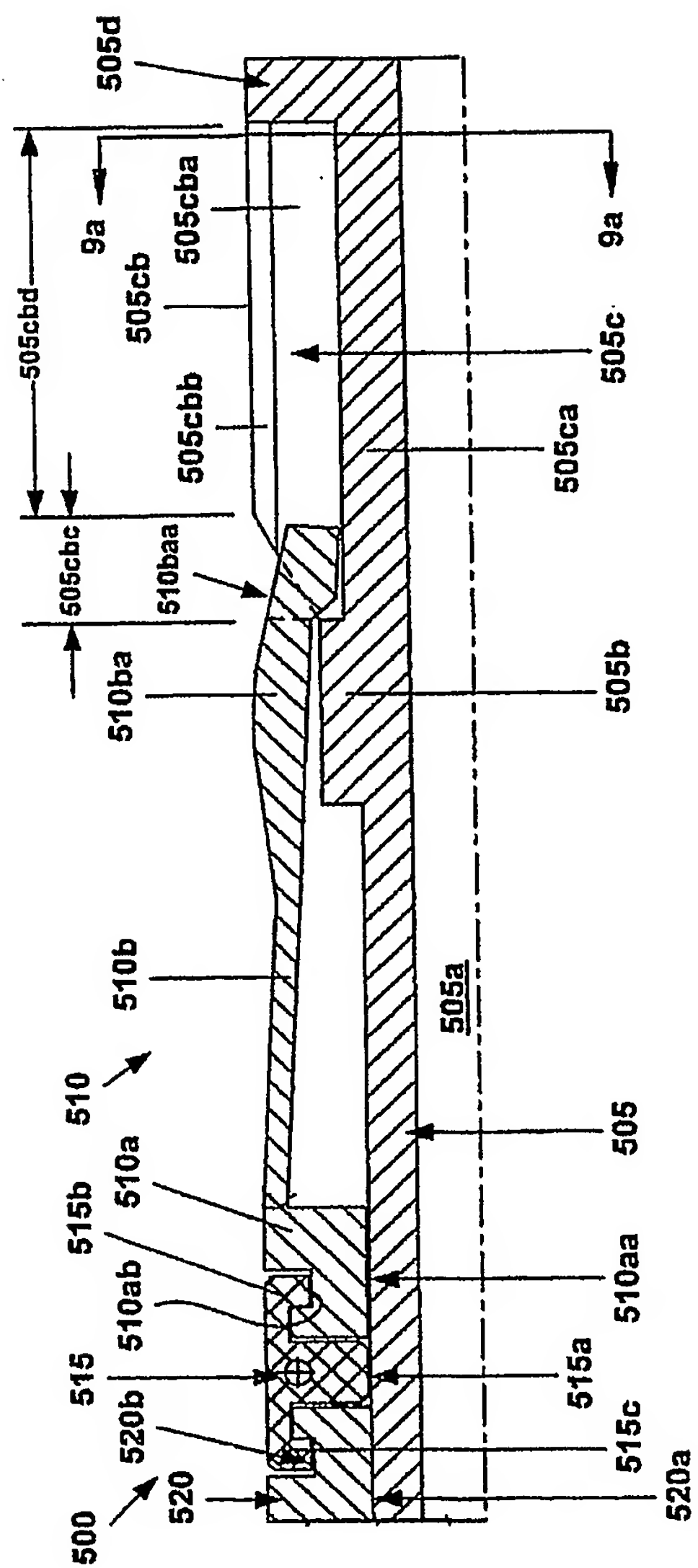
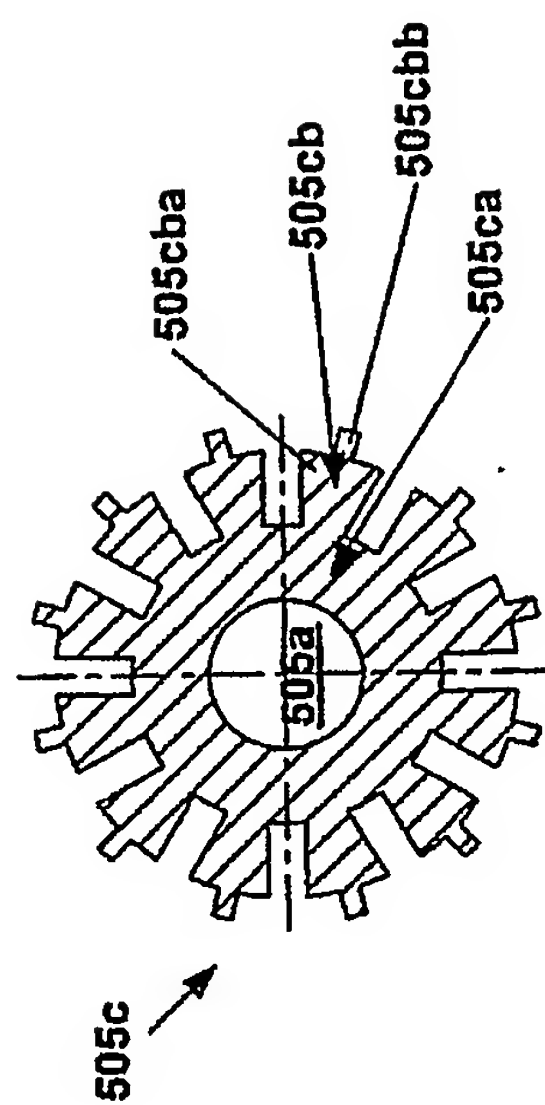


Fig. 8c

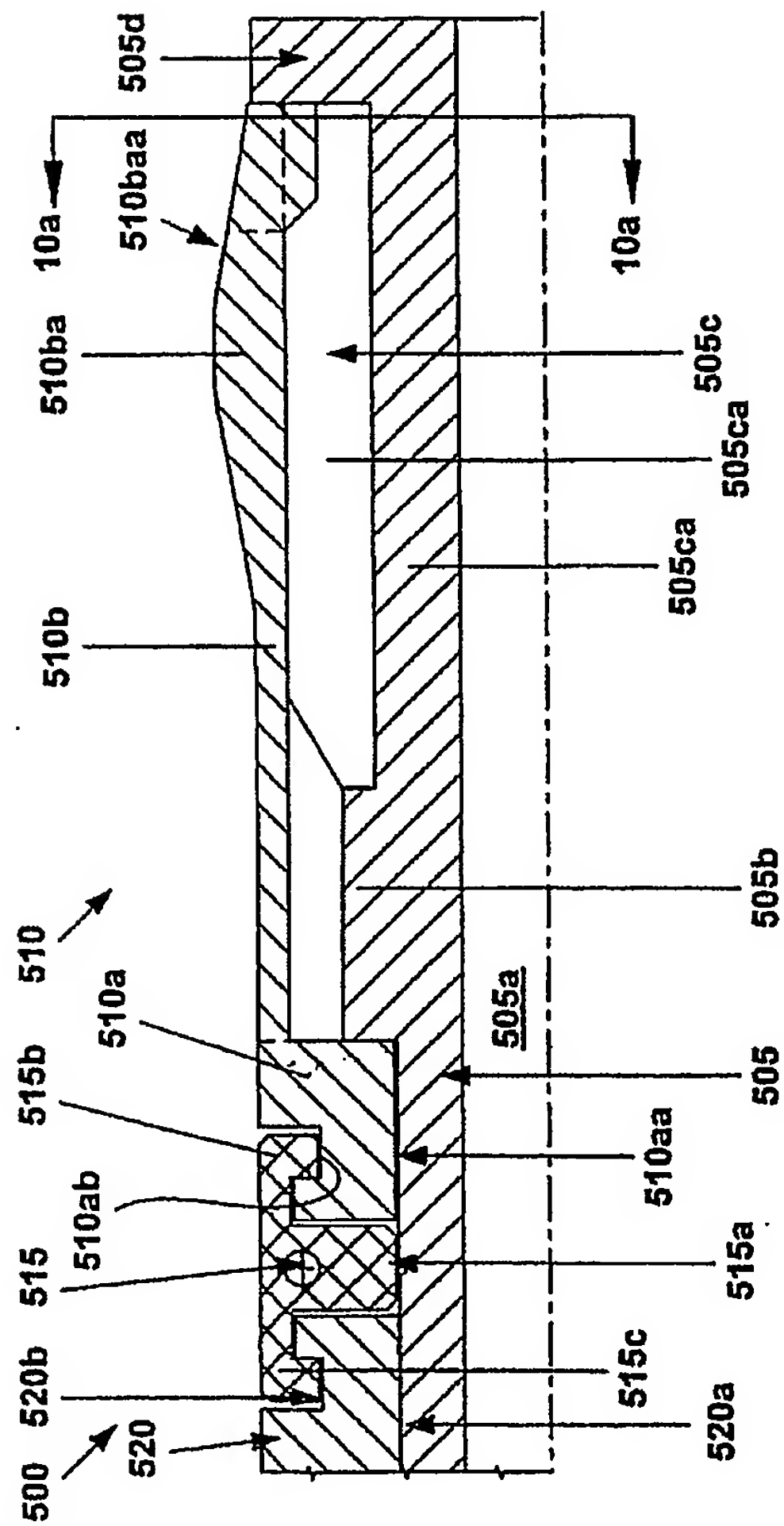




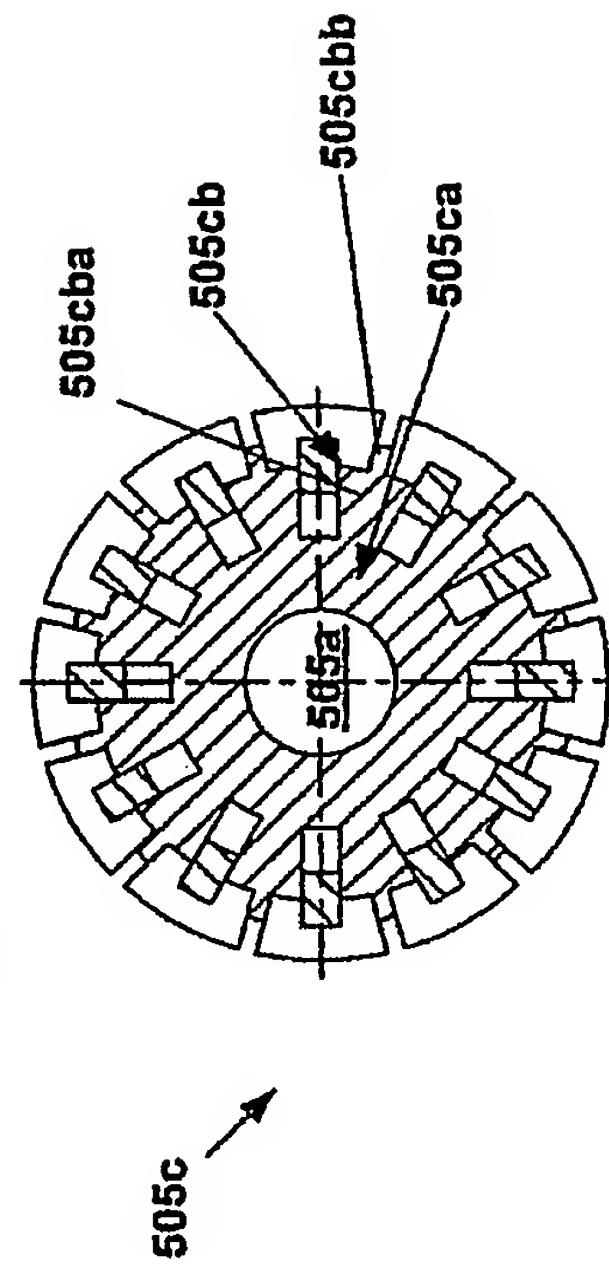
**Fig. 9**



**Fig. 9a**



**Fig. 10**

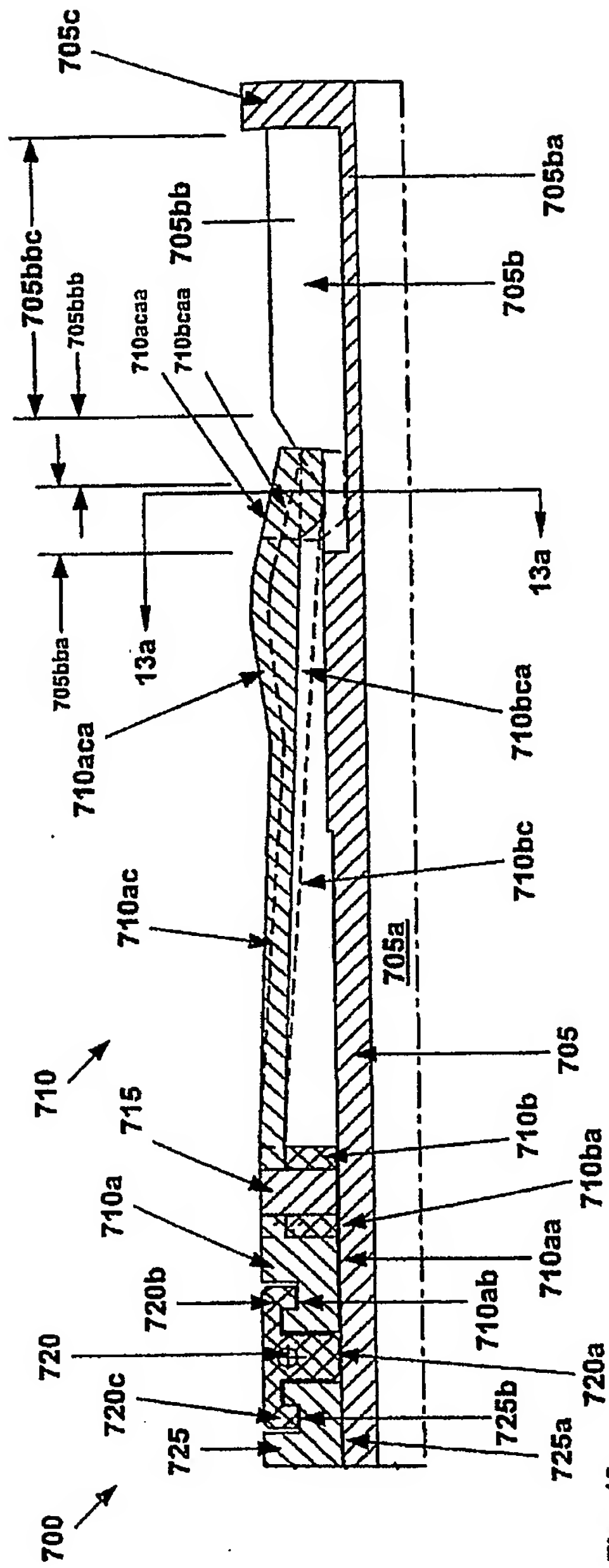


**Fig. 10a**

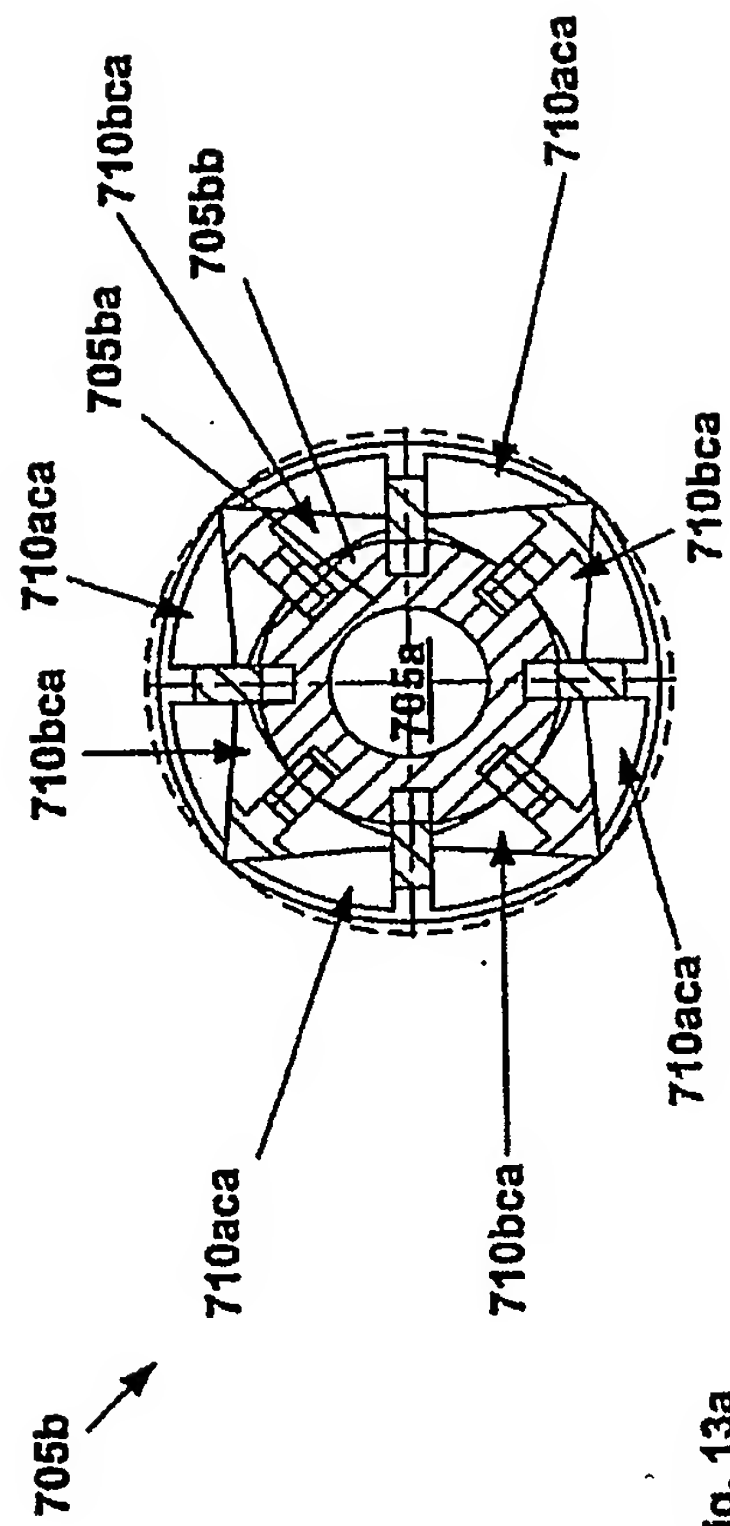








**Fig. 13**



**Fig. 13a**

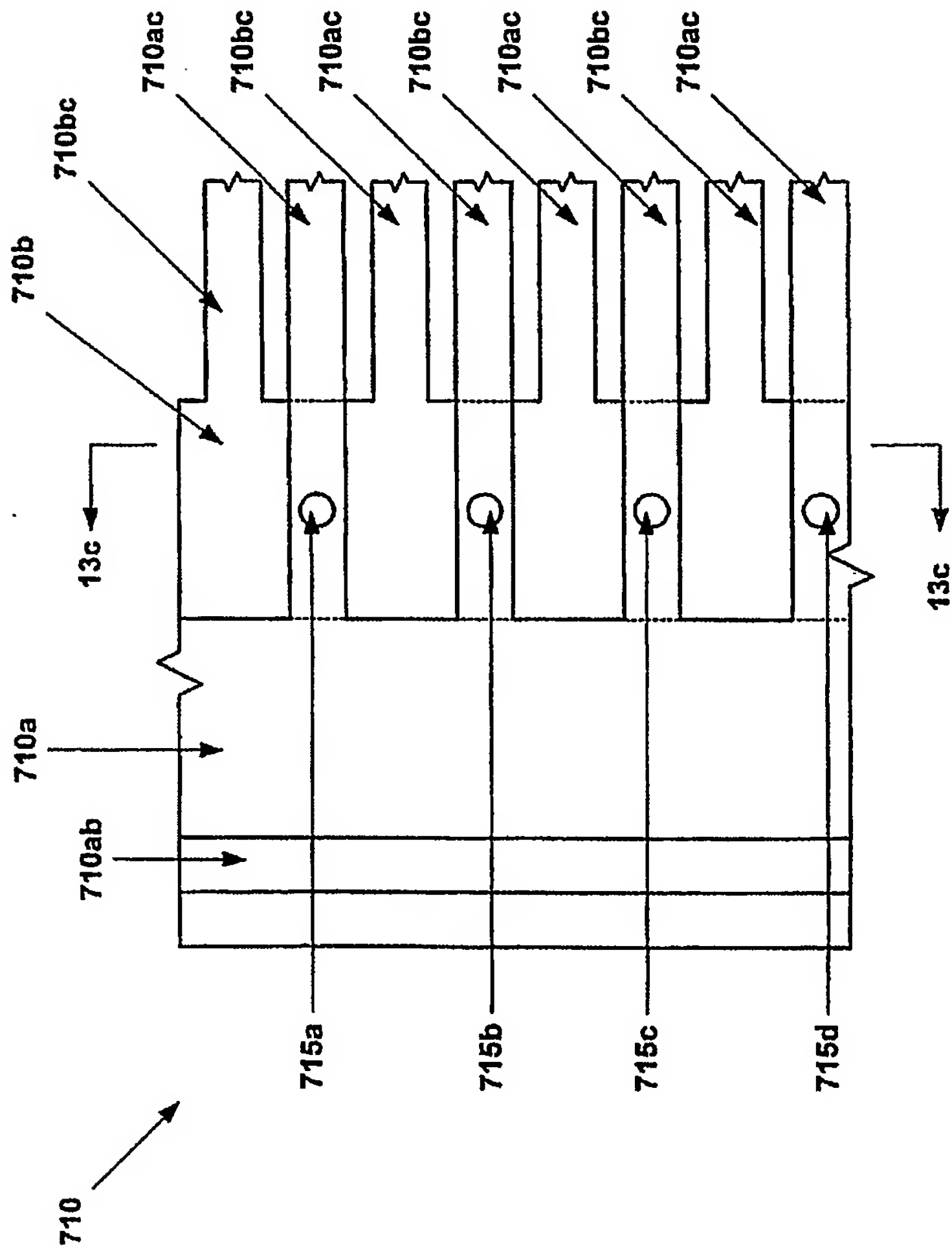


Fig. 13b

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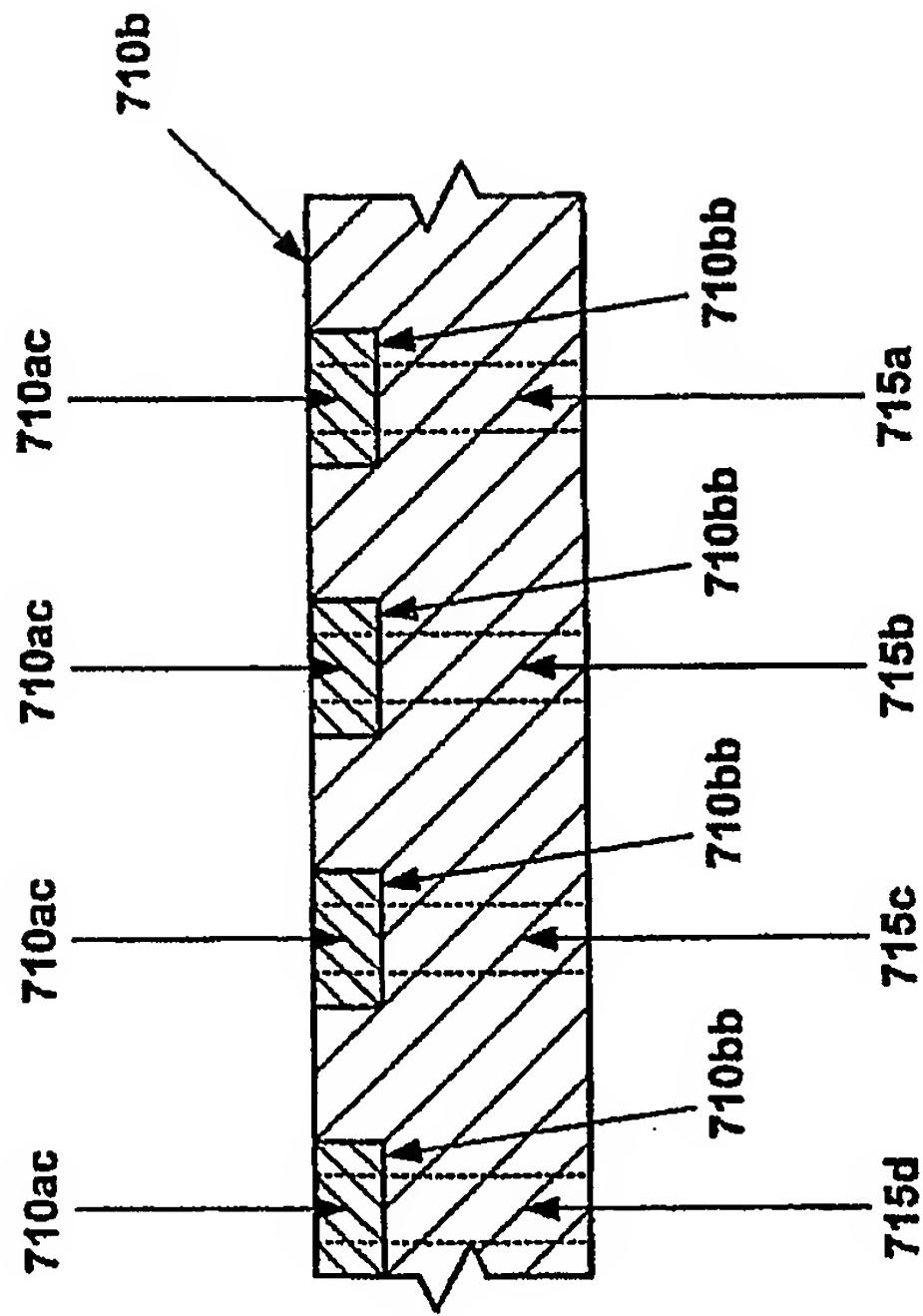
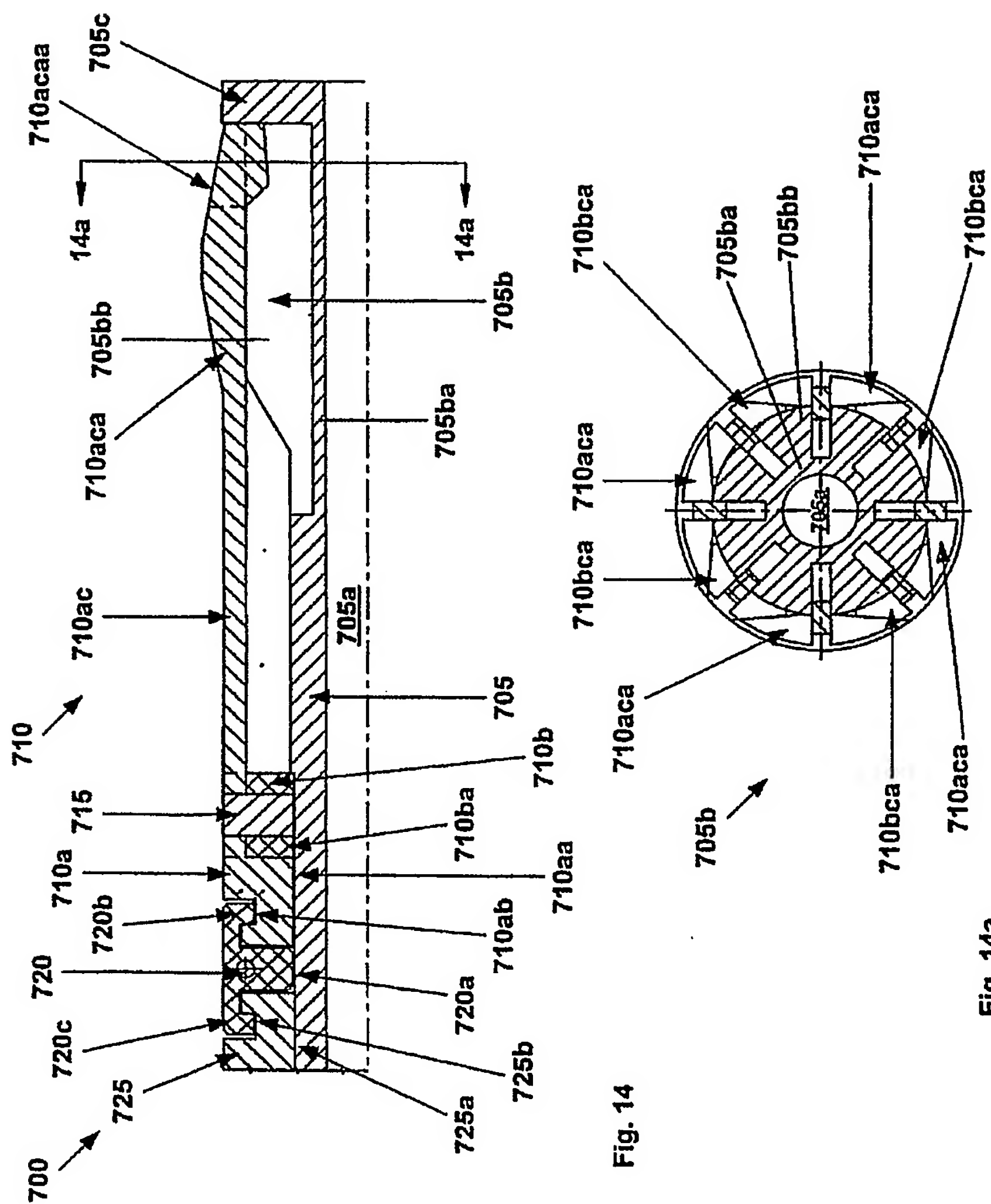


Fig. 13c





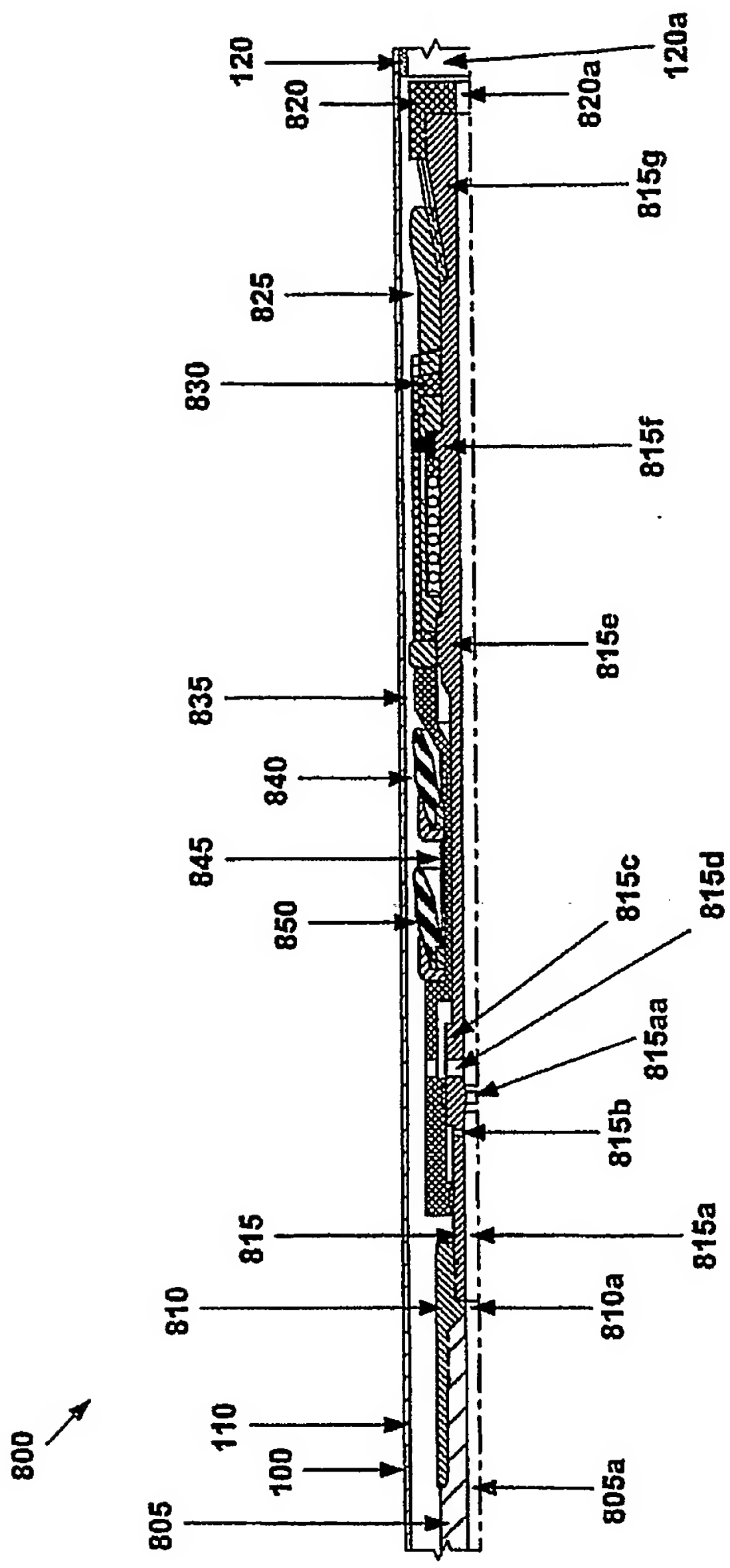


Fig. 15

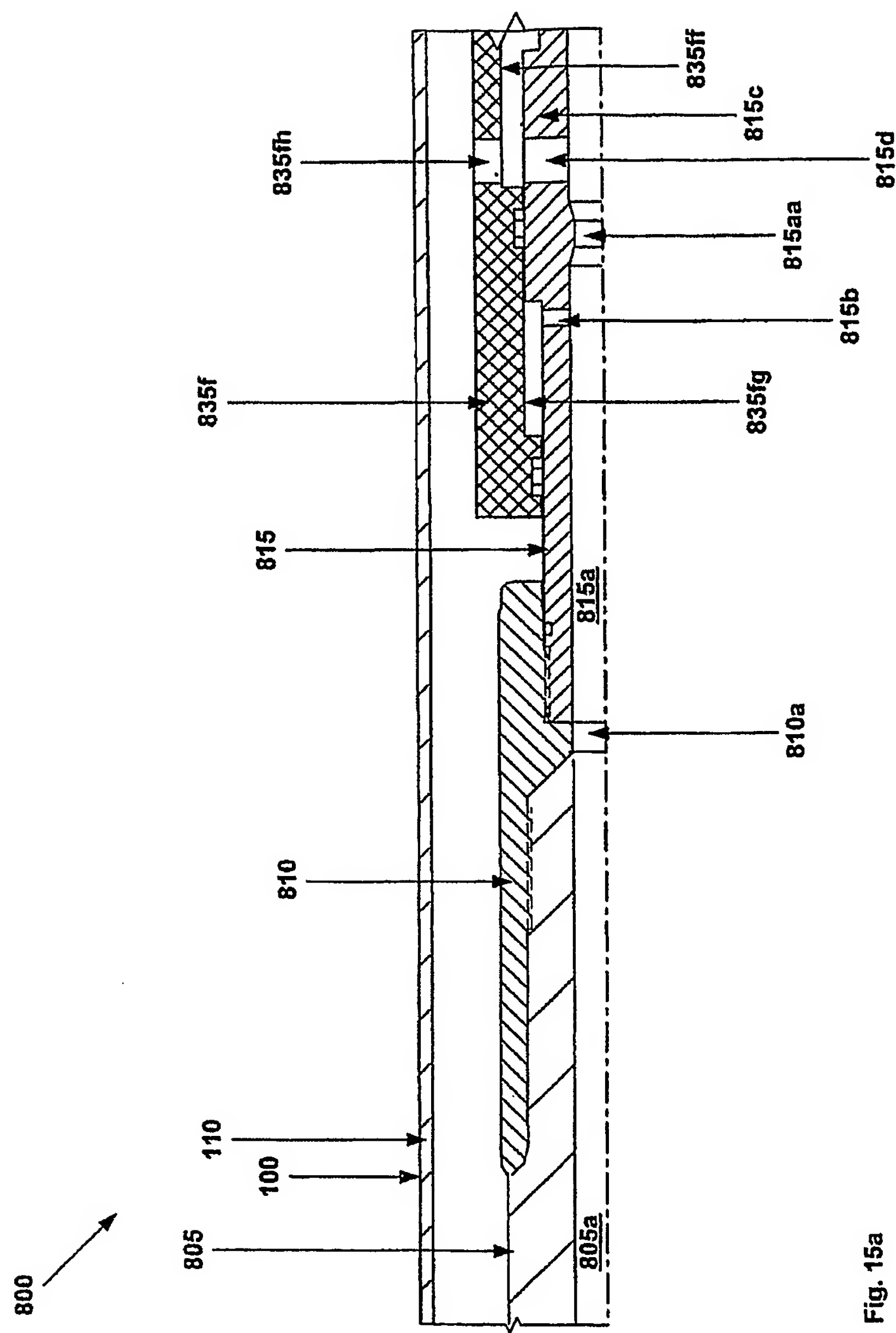


Fig. 15a

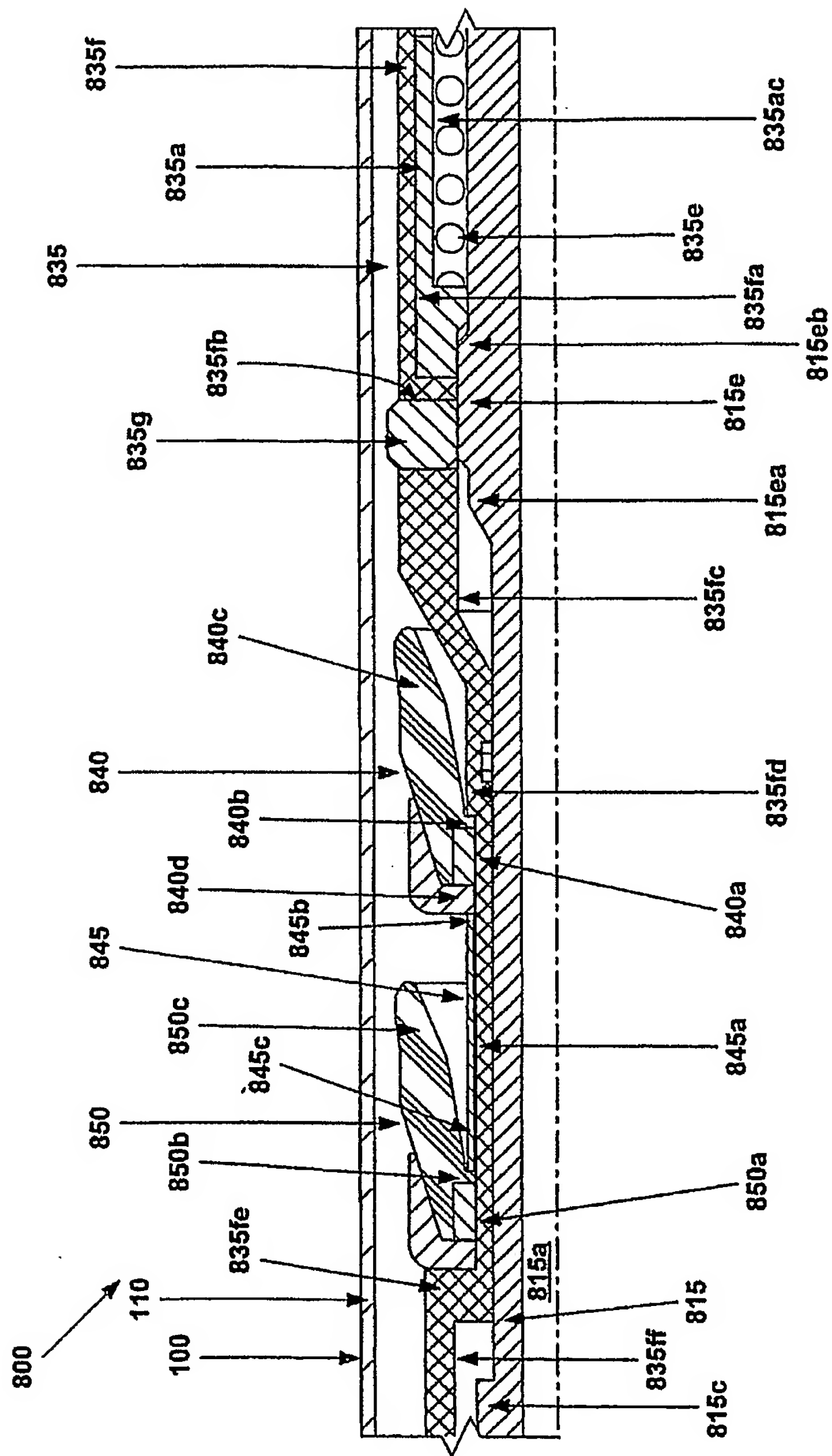
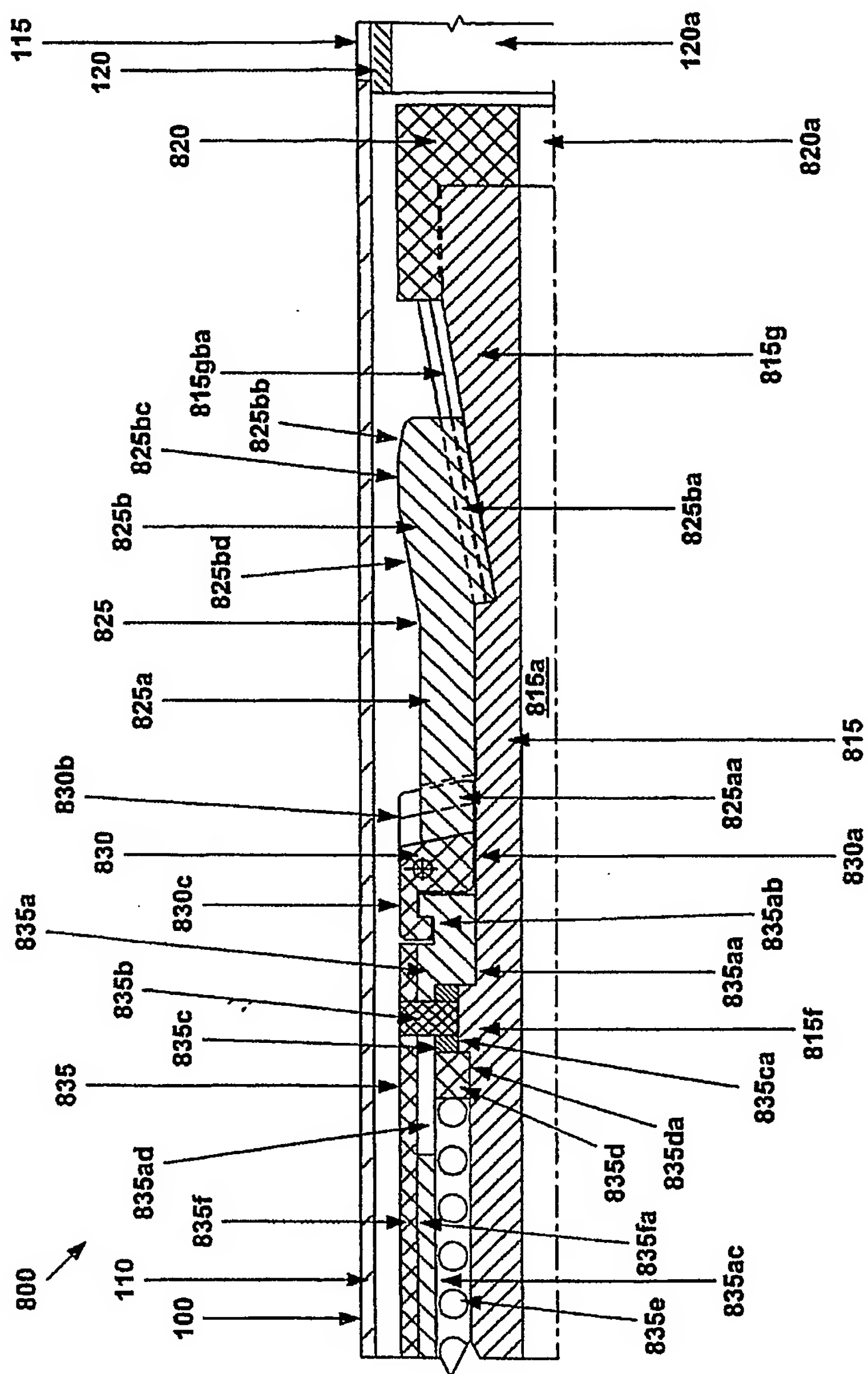


Fig. 15b



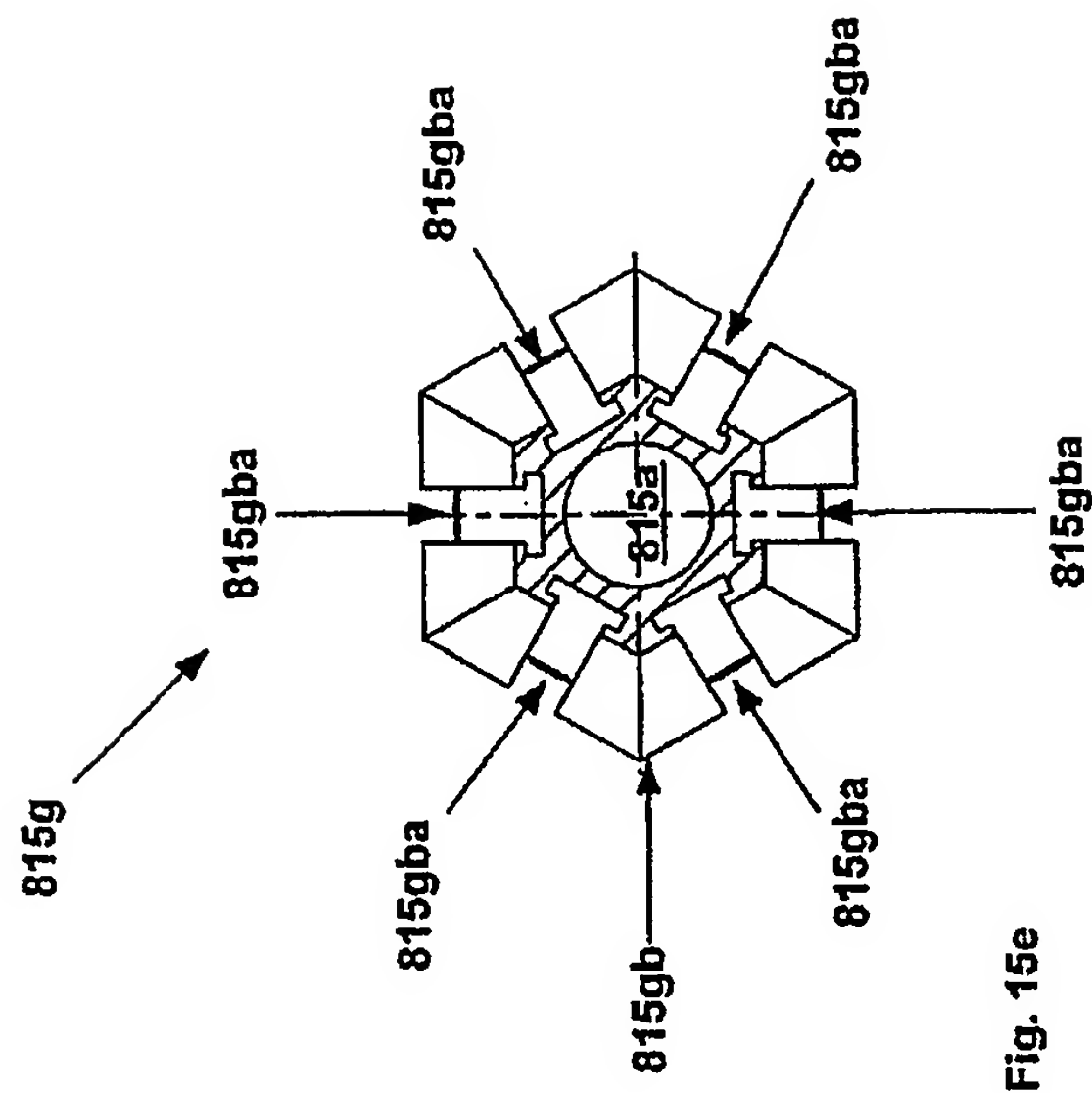


Fig. 15e

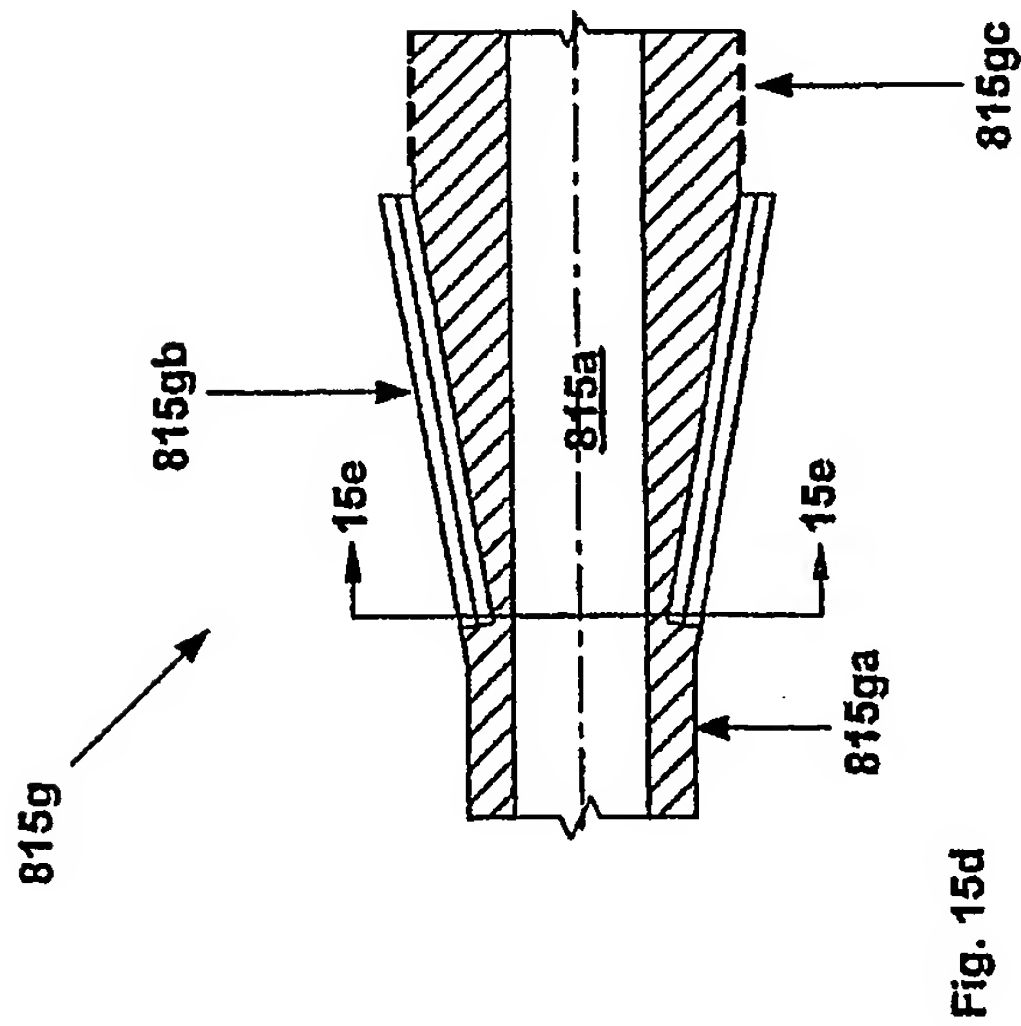


Fig. 15d

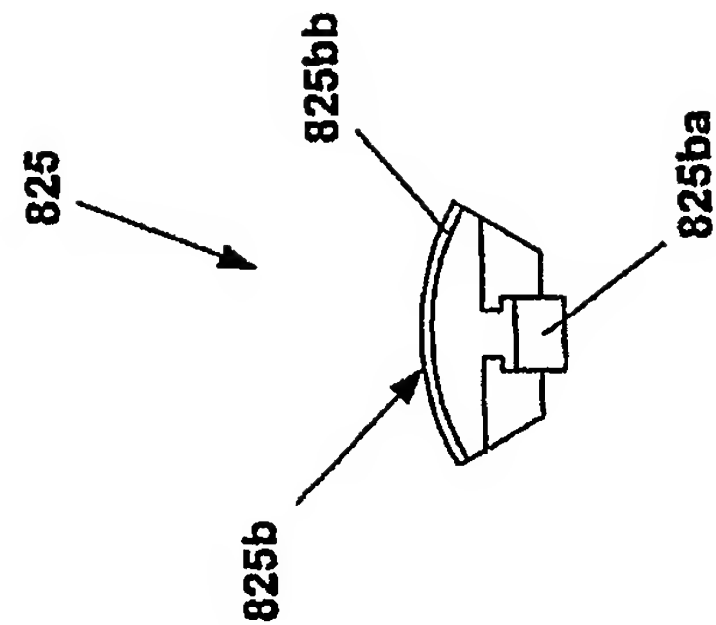


Fig. 15g

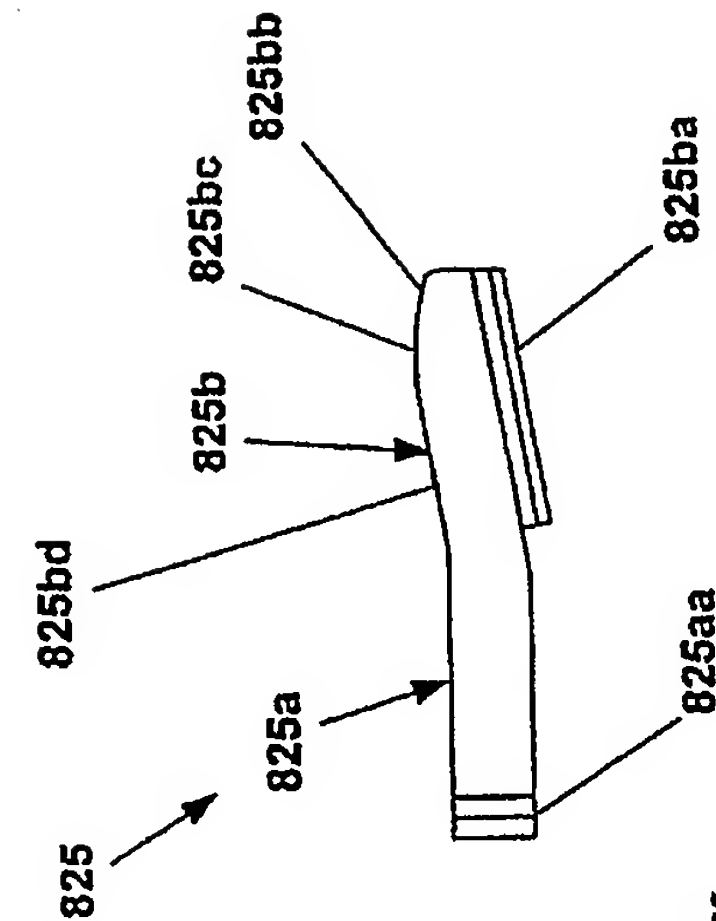


Fig. 15f

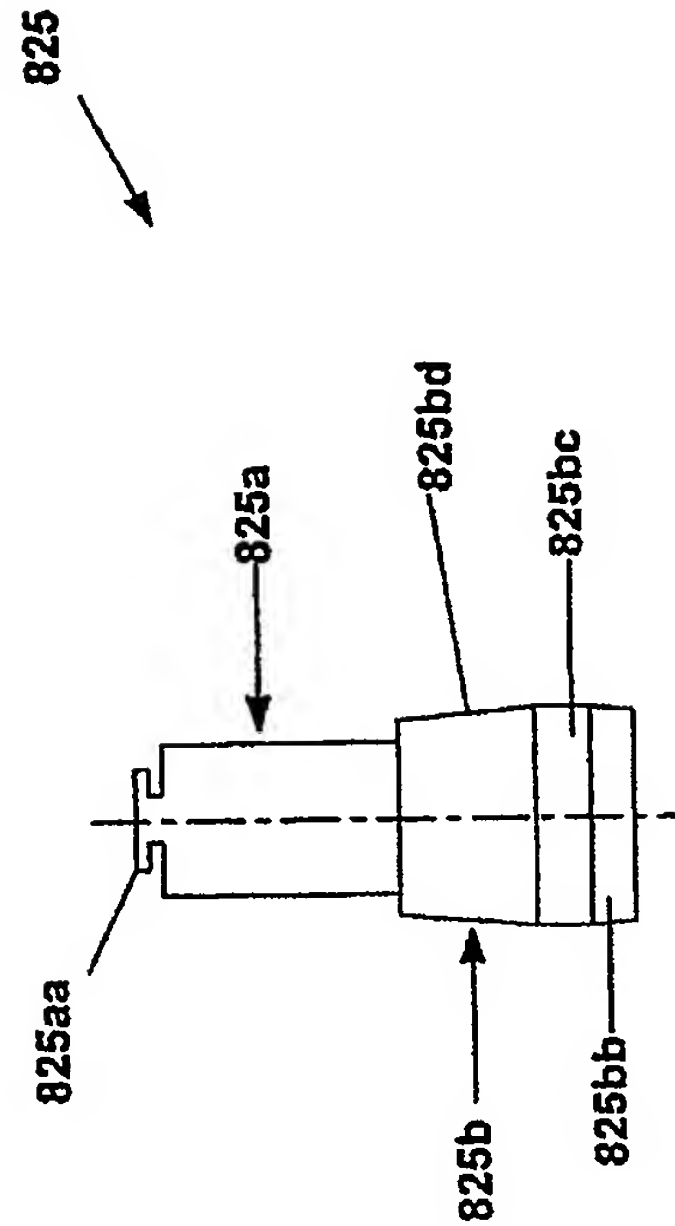


Fig. 15h



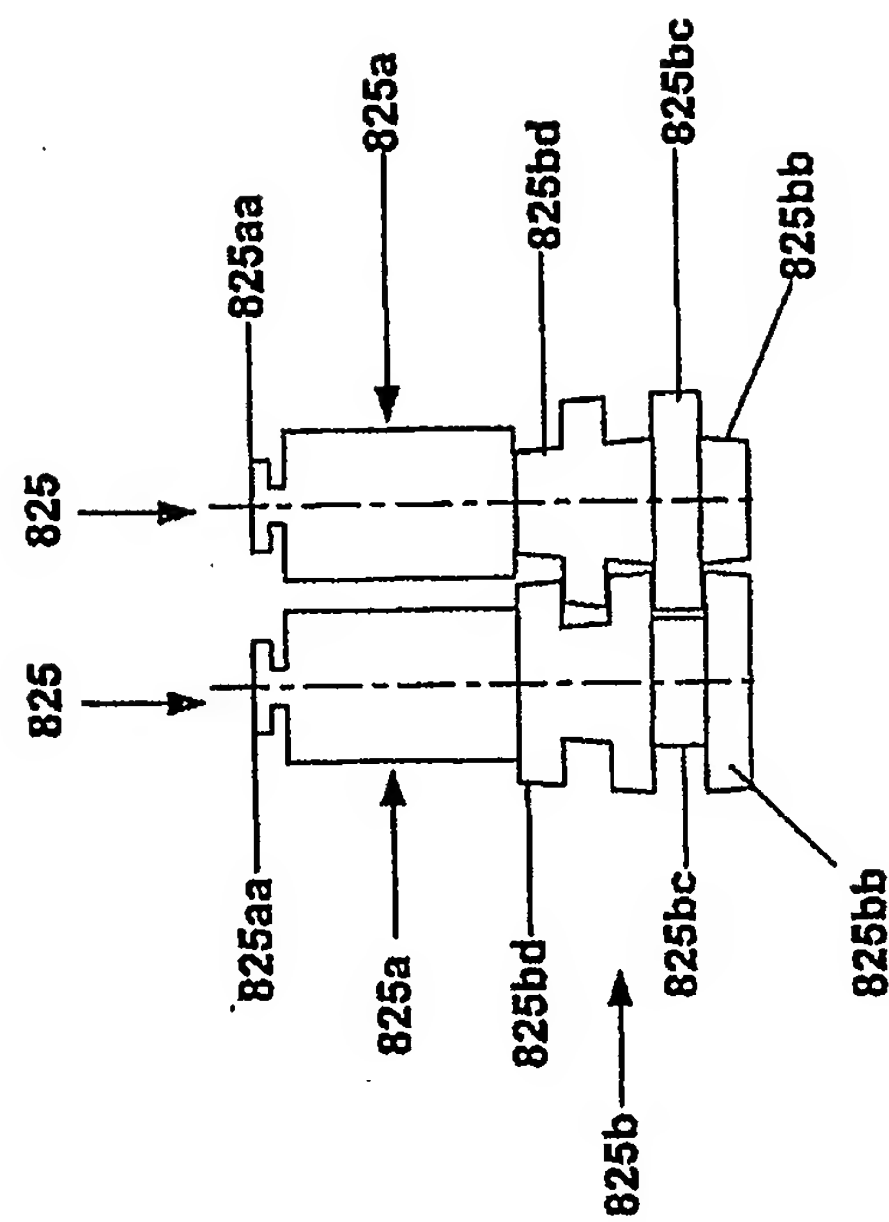


Fig. 15i

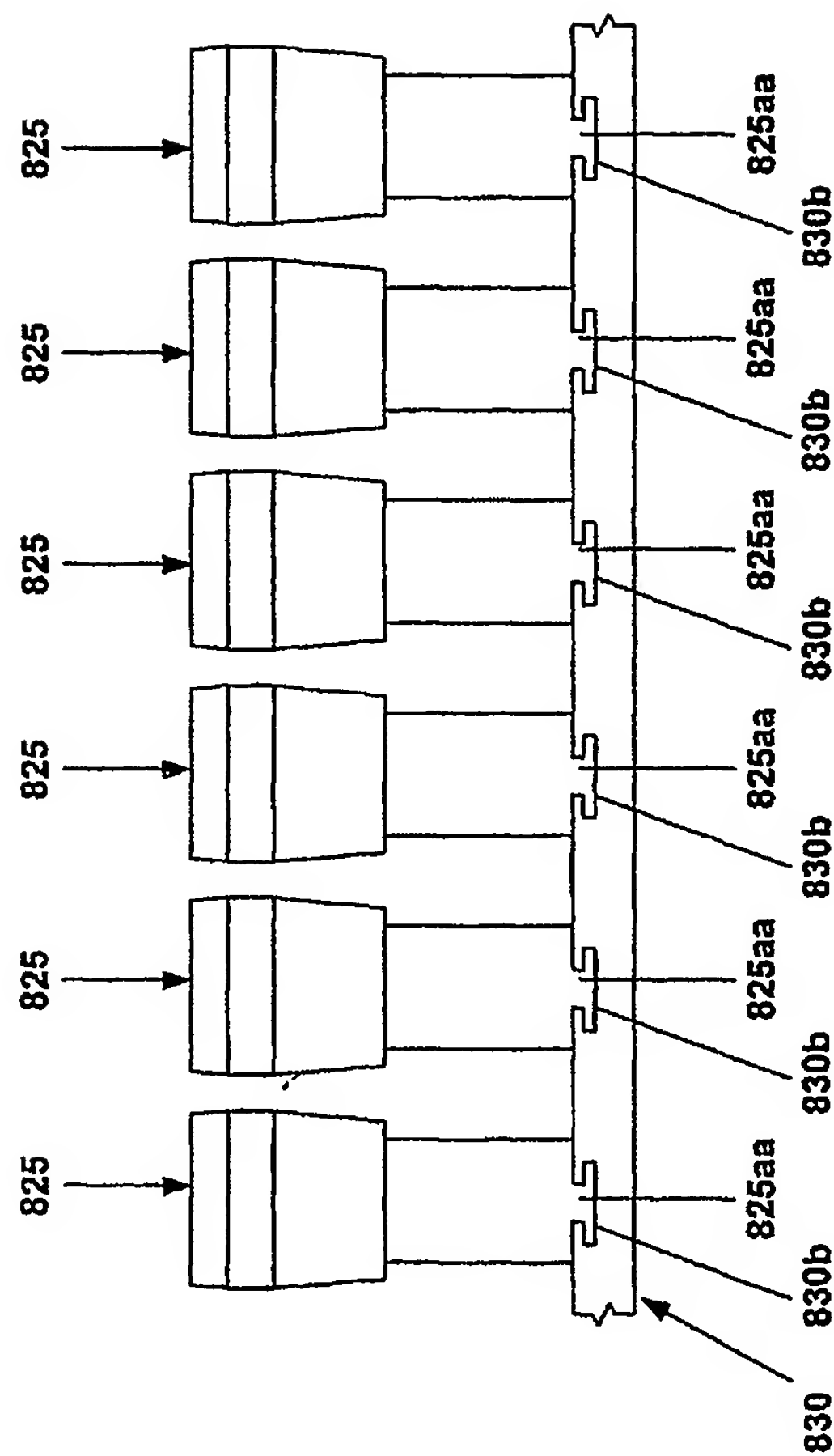


Fig. 15j

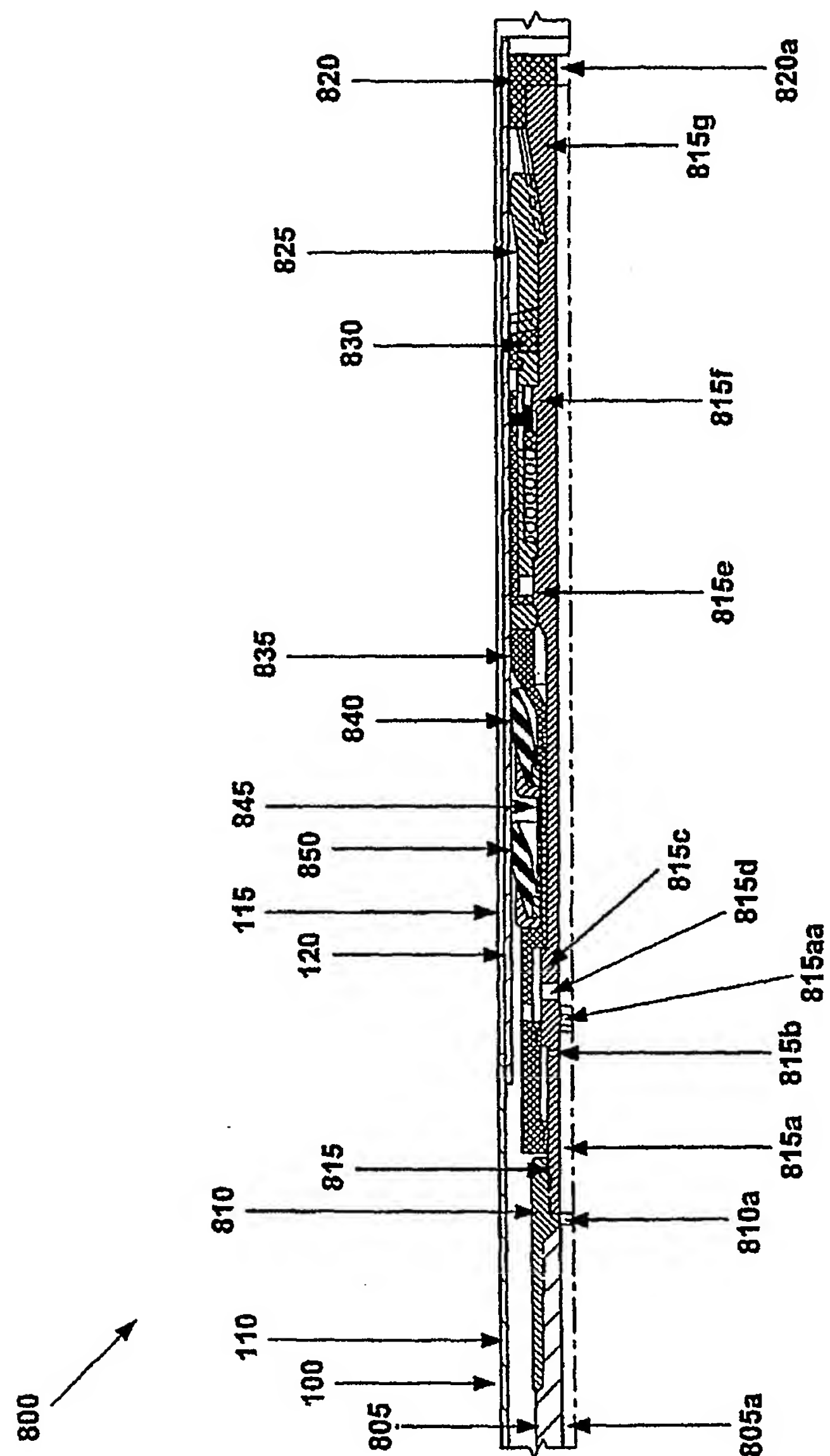


Fig. 16

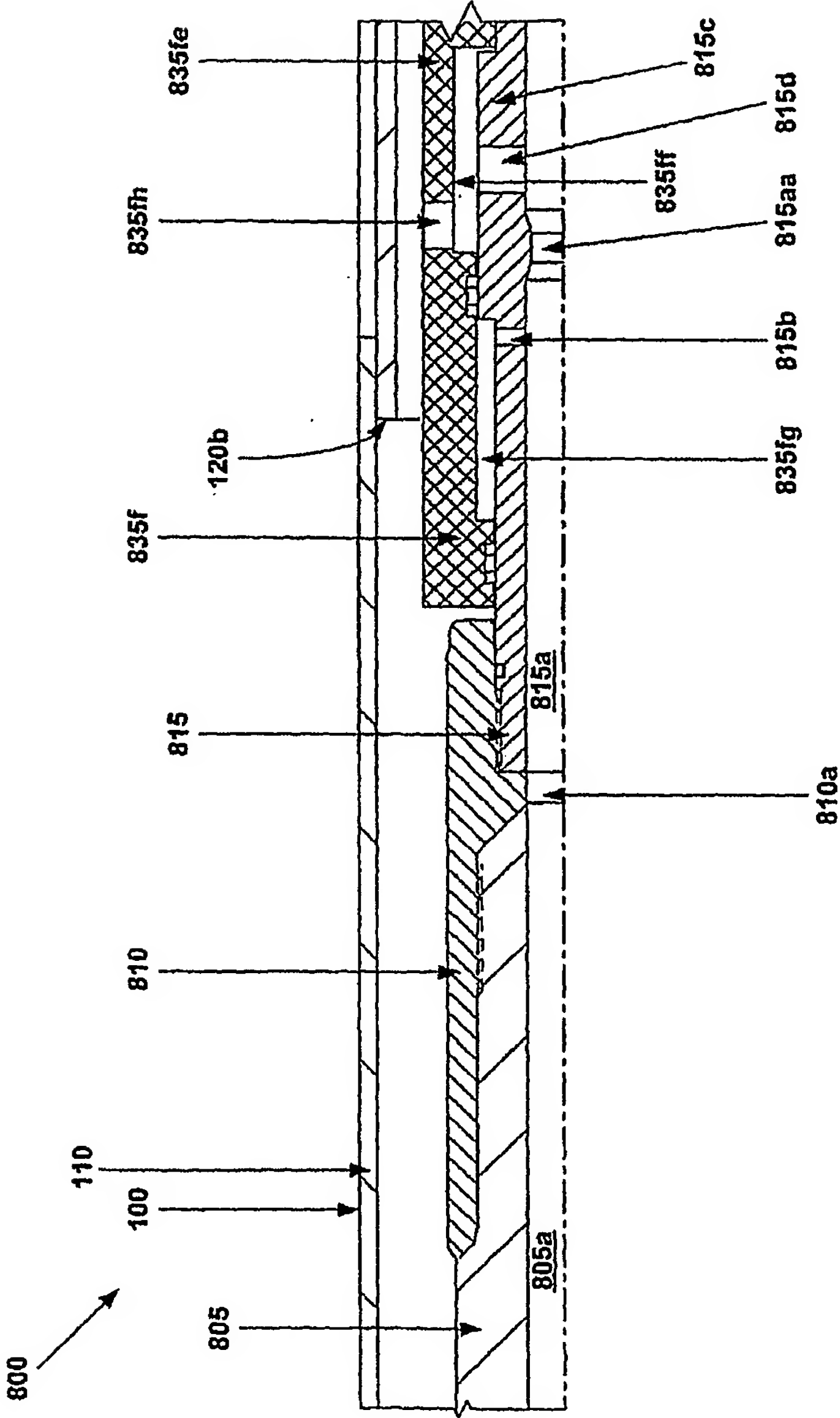


Fig. 16a

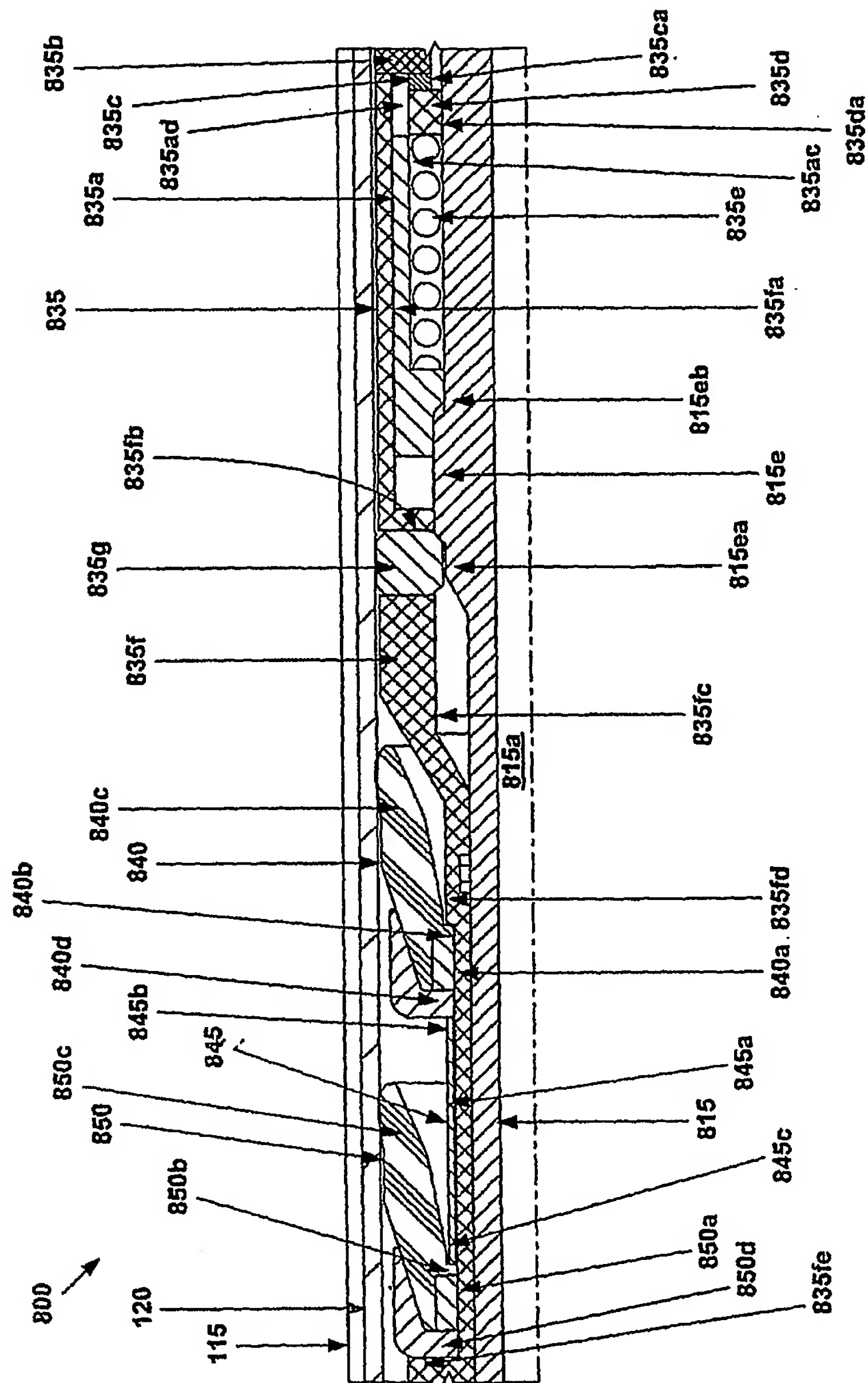


Fig. 16b

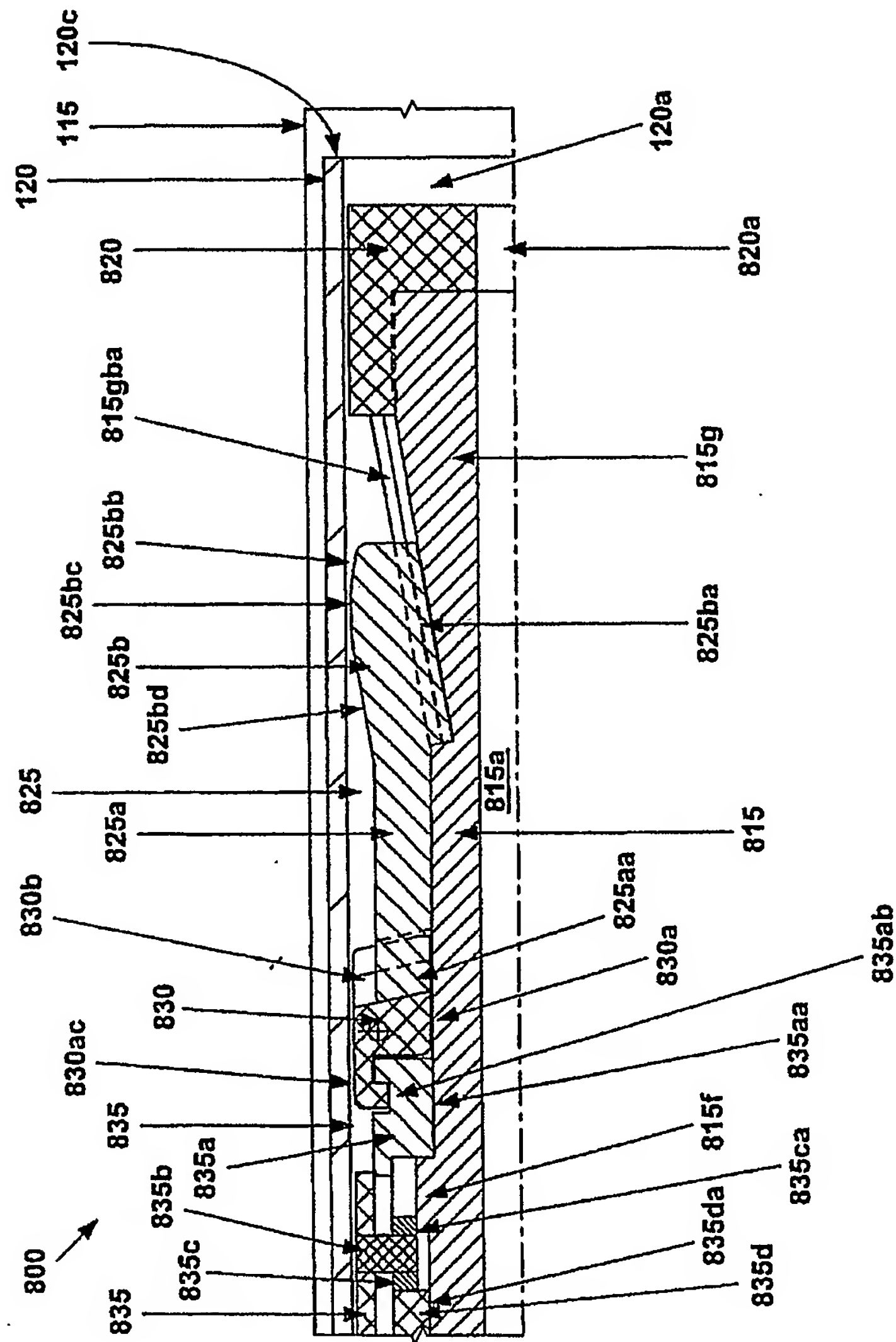


Fig. 16c



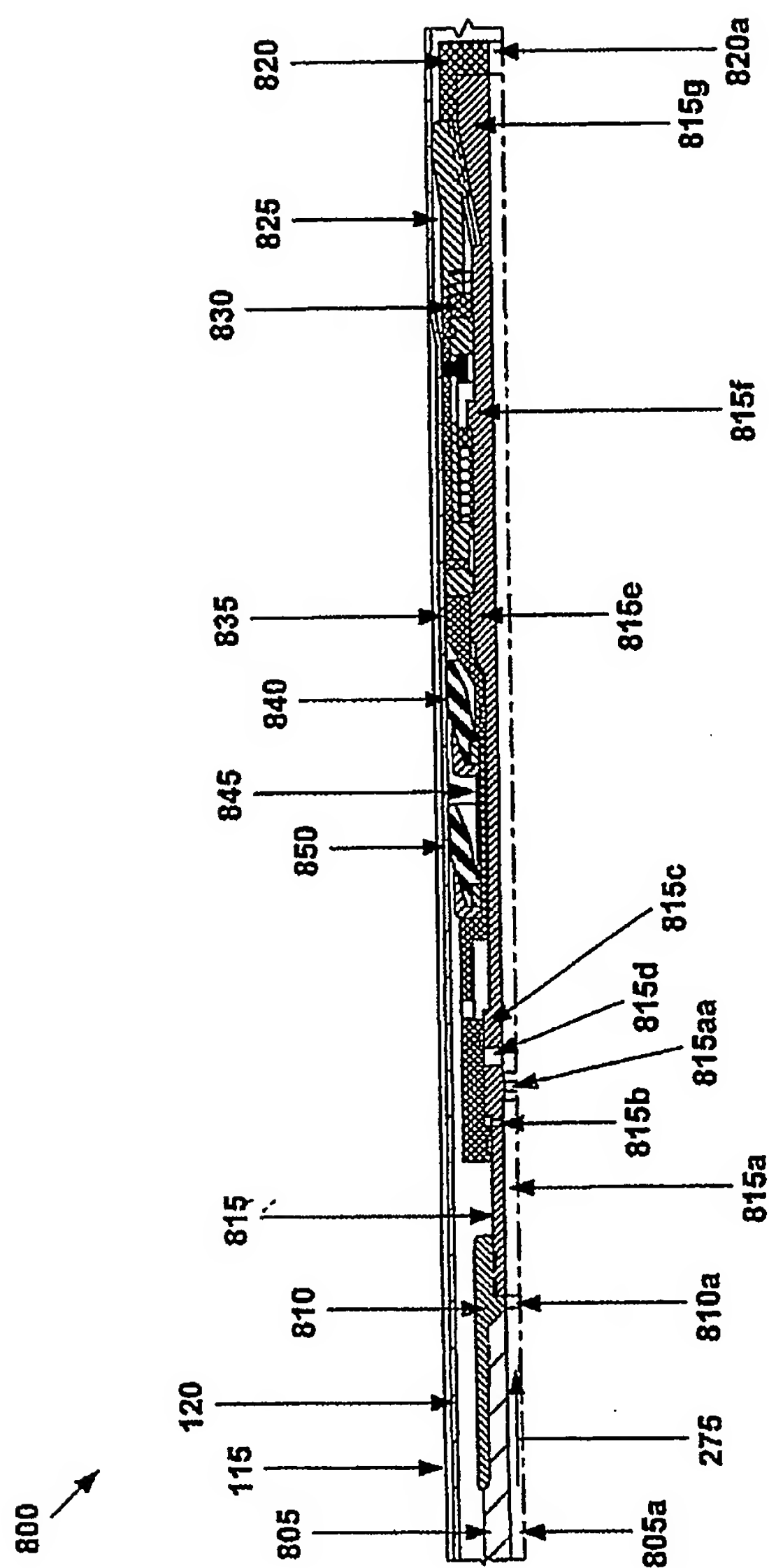


Fig. 17

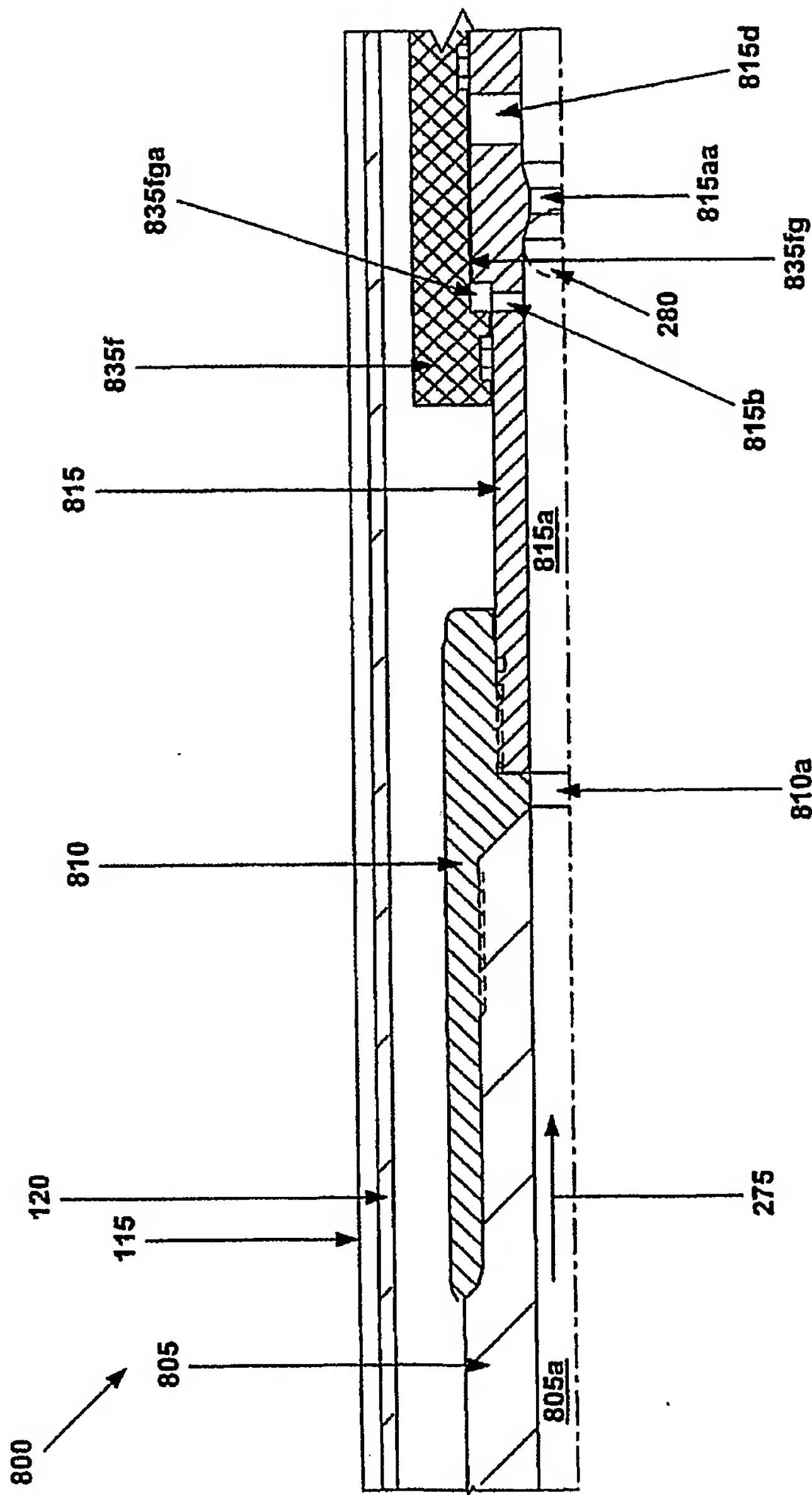


Fig. 17a

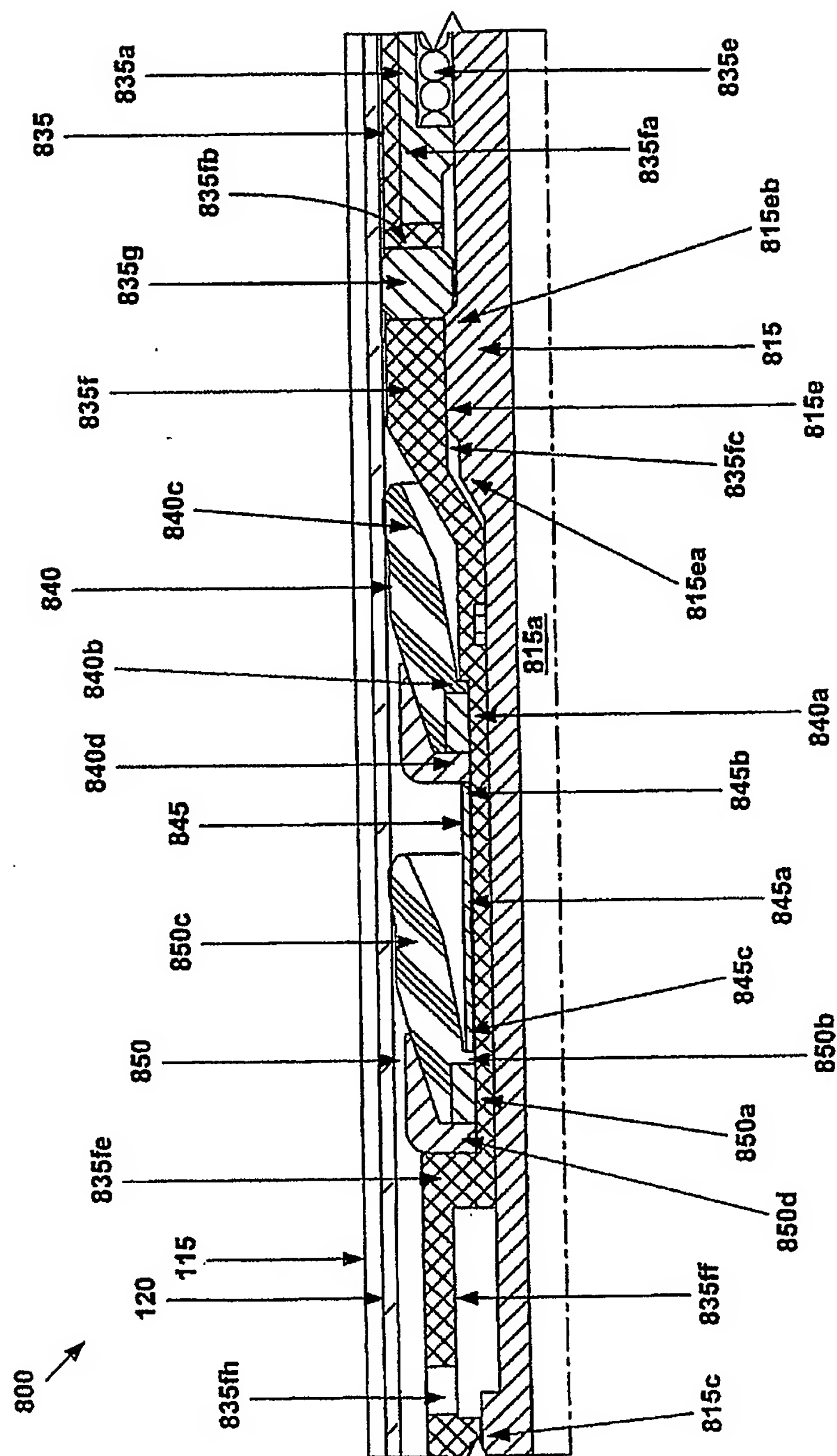


Fig. 17b

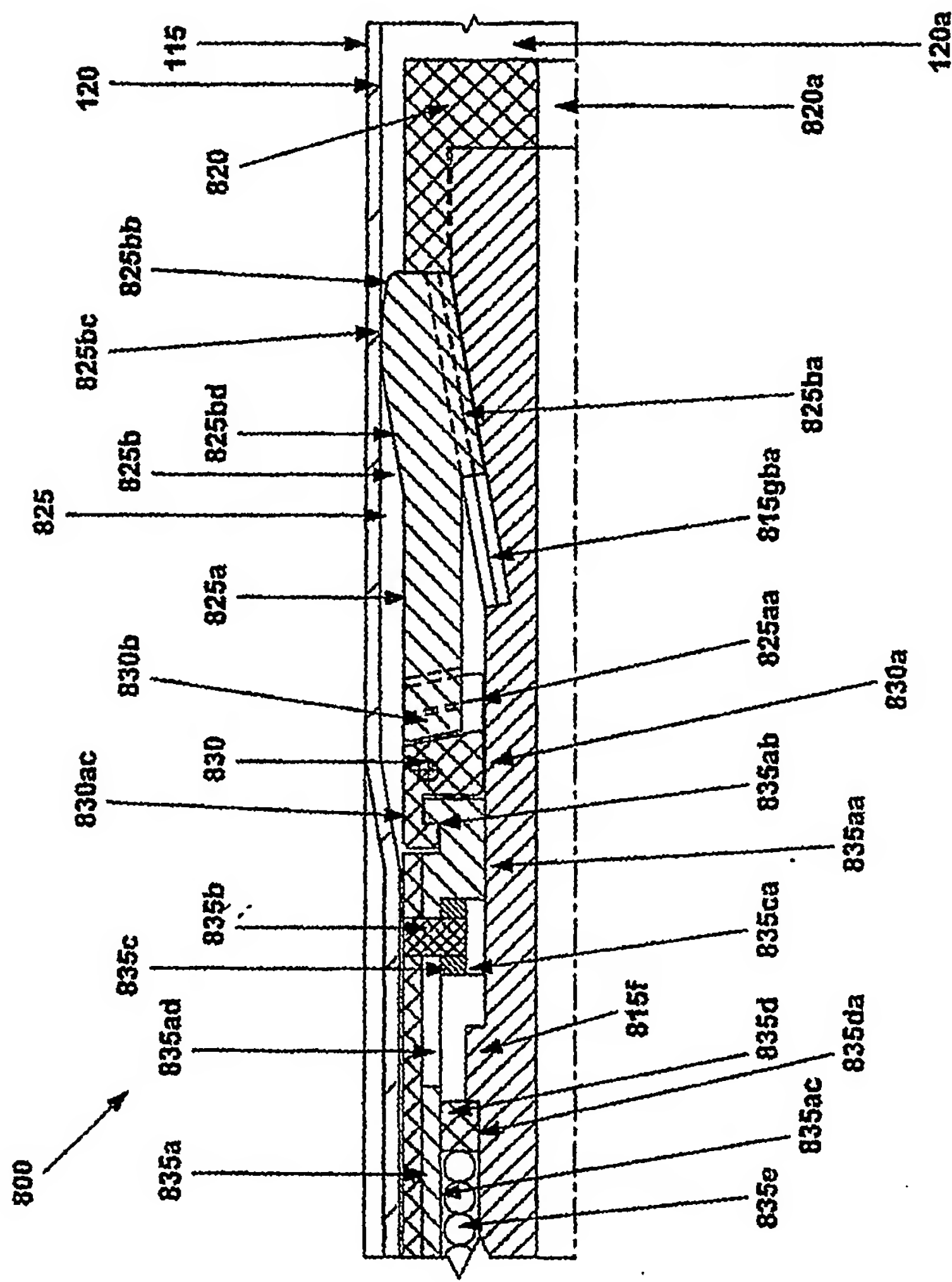


Fig. 17c

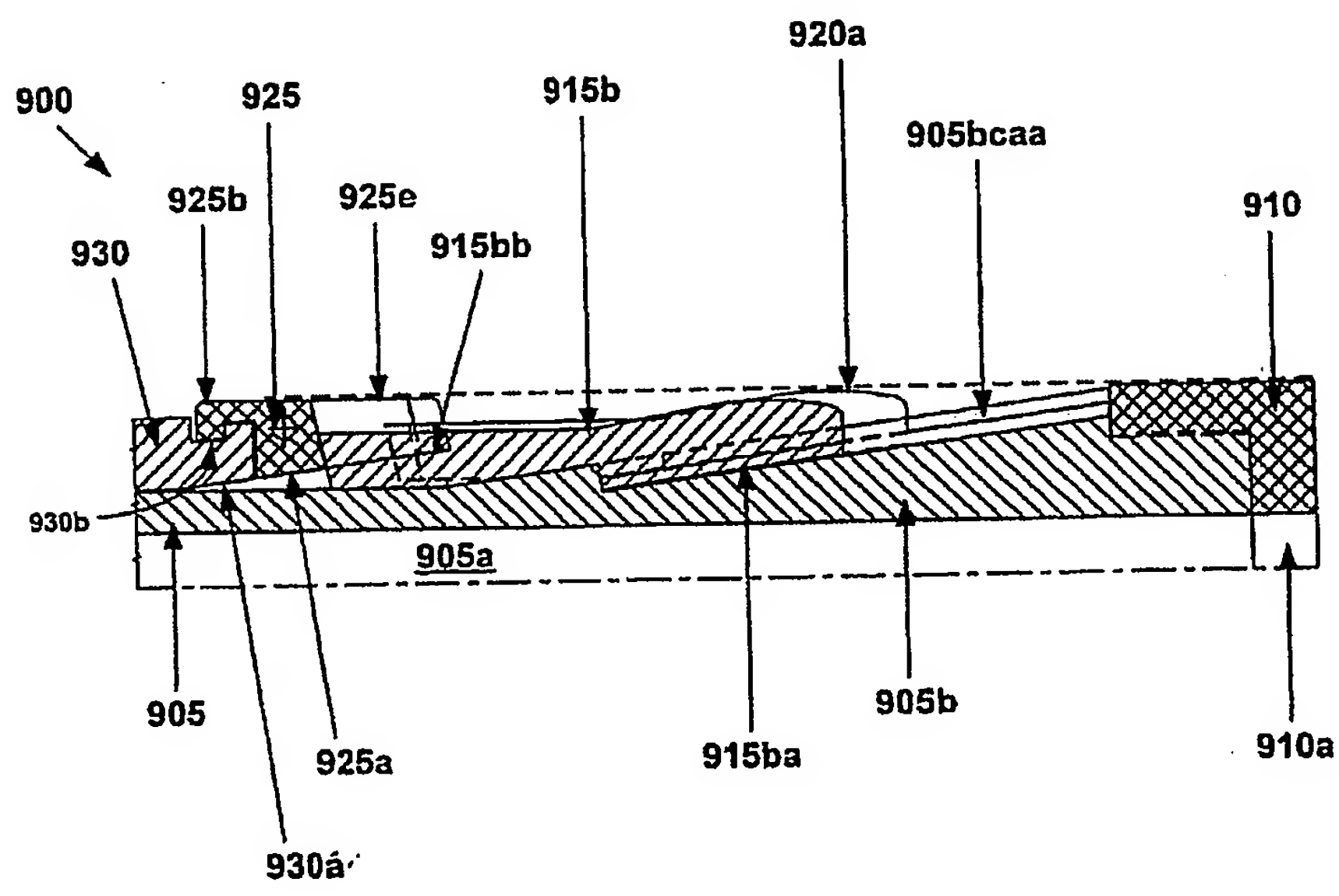
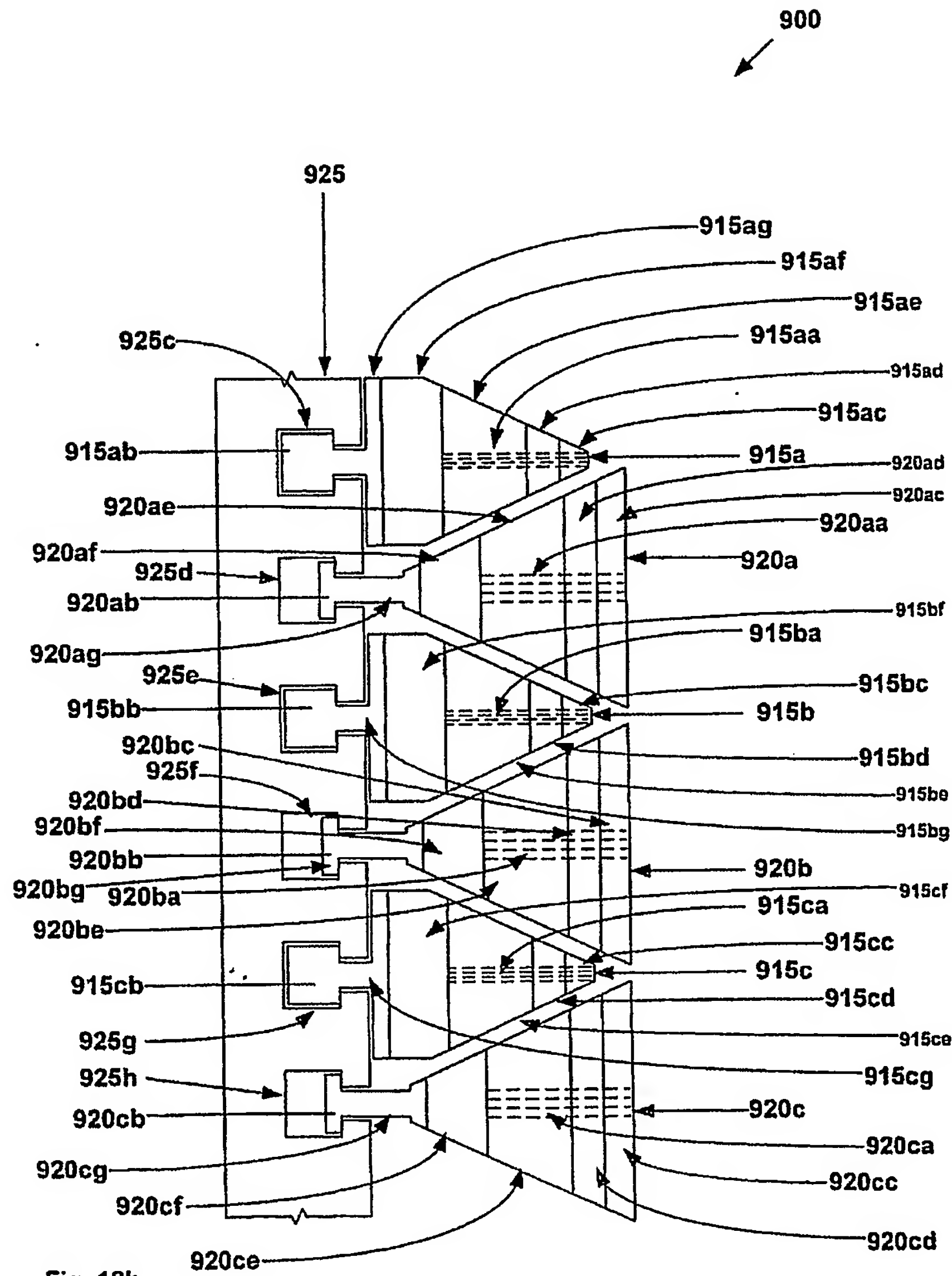
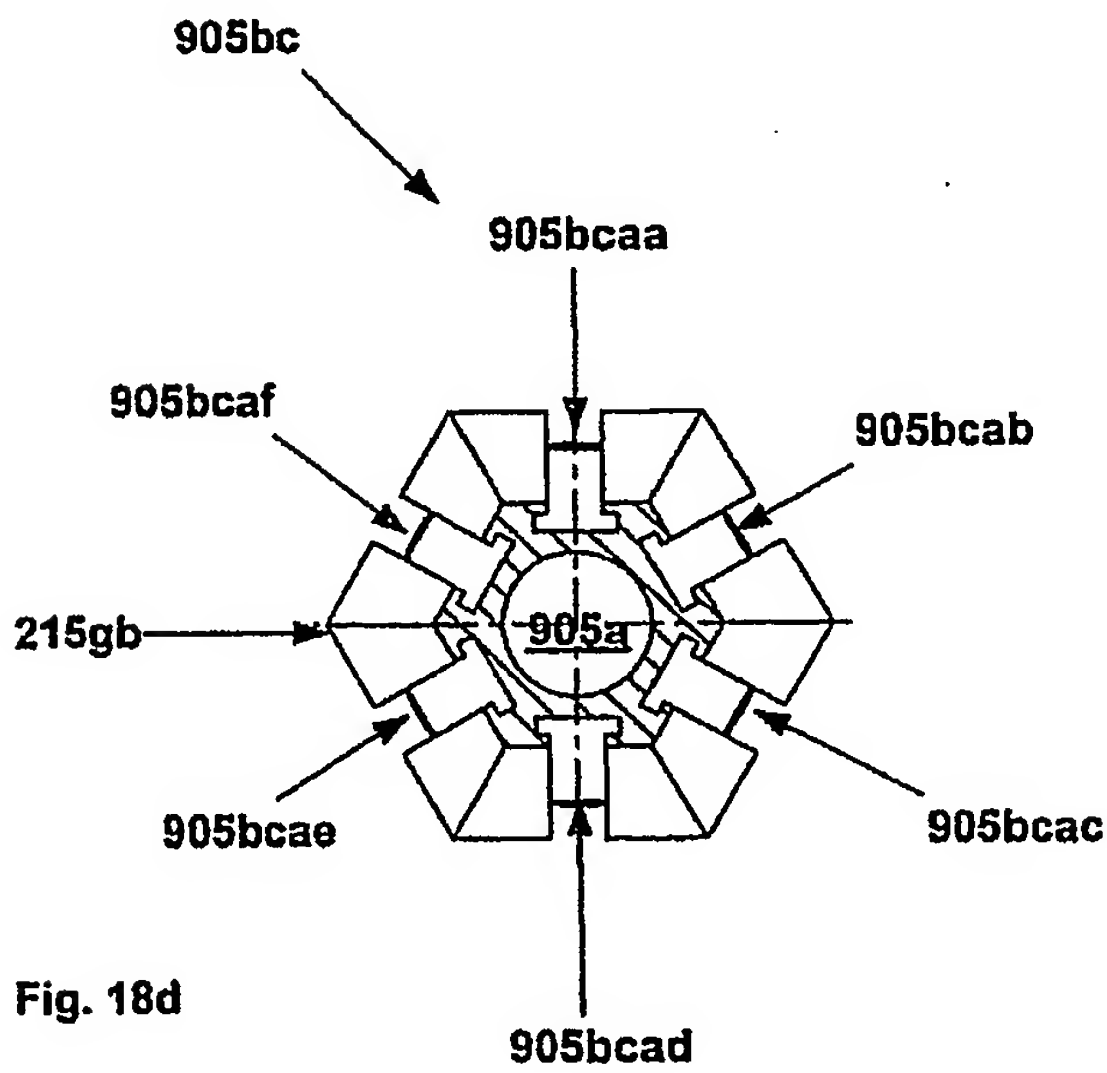
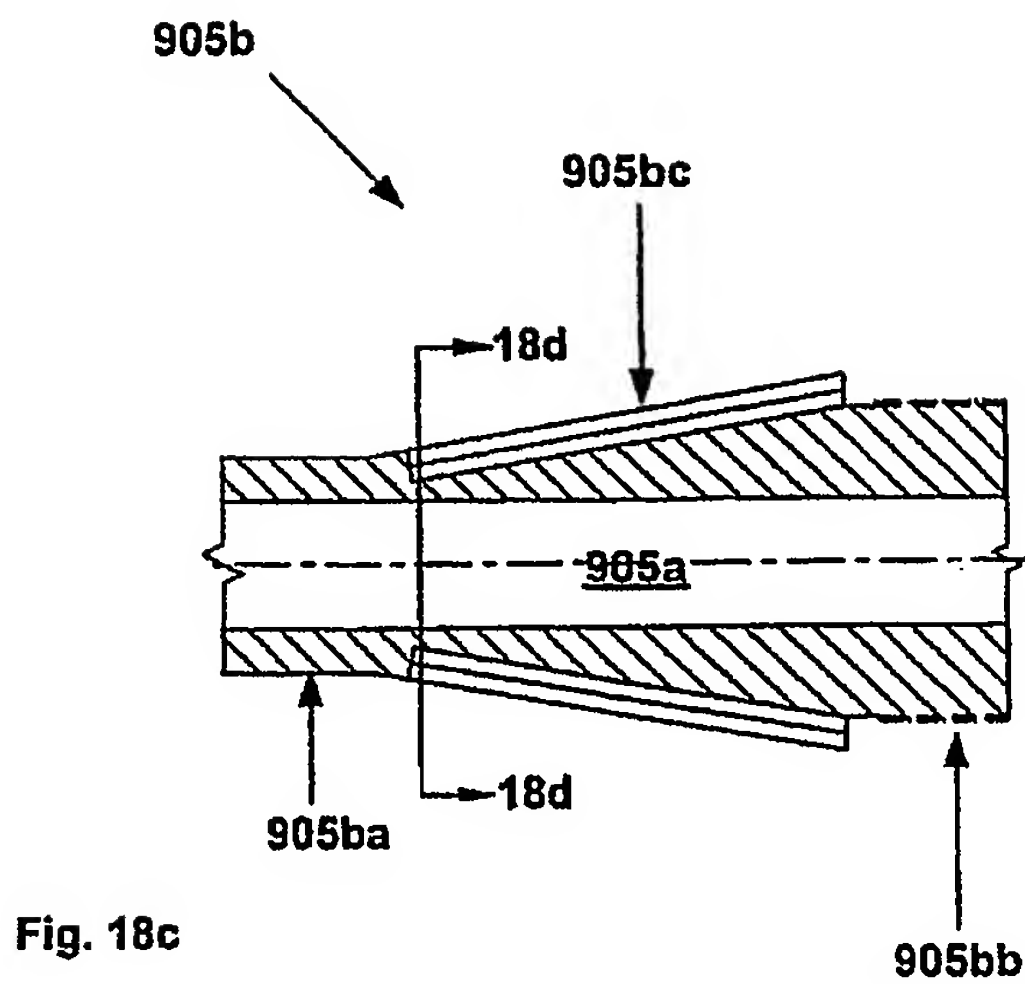
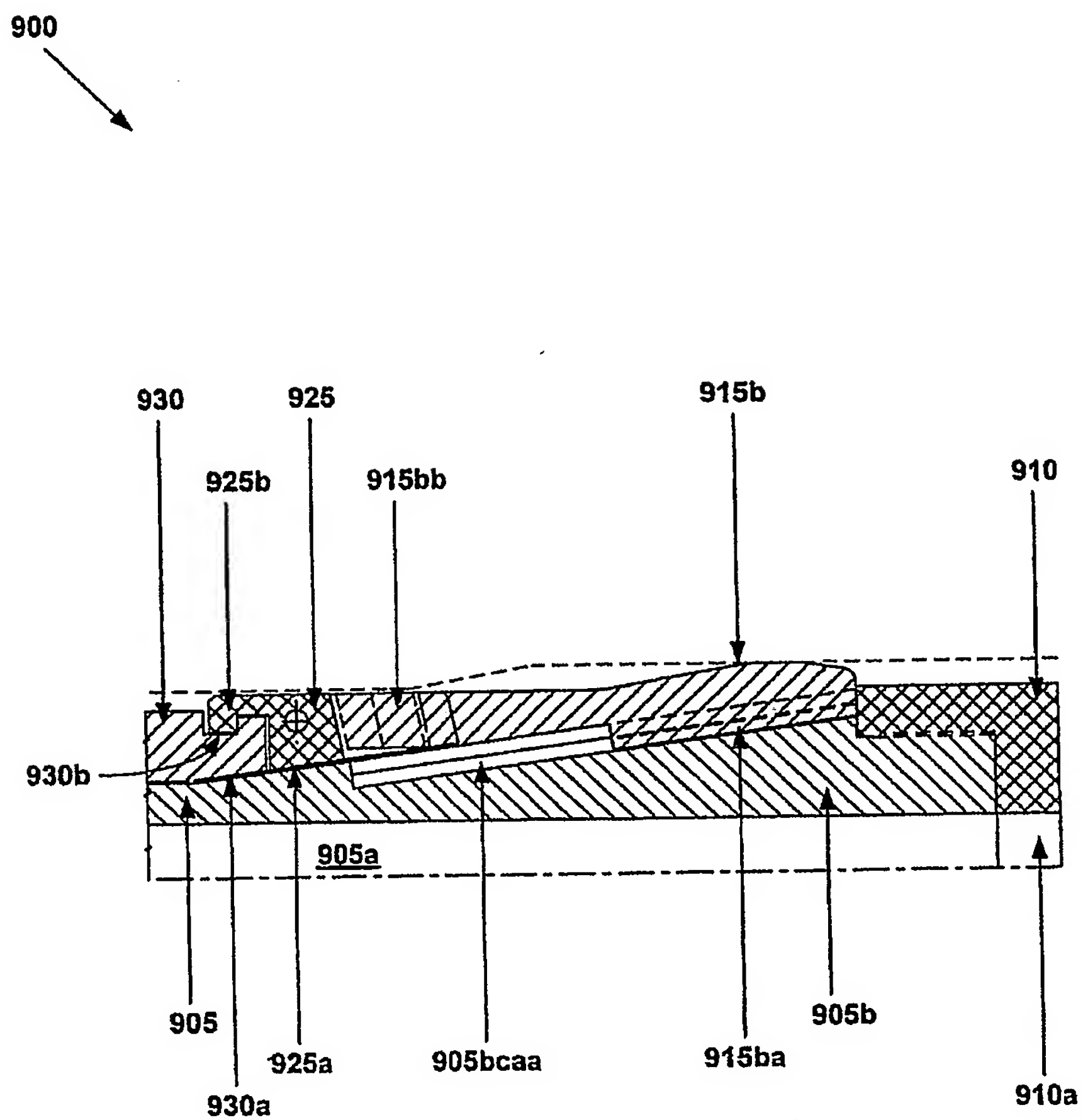


Fig. 18a









**Fig. 19a**

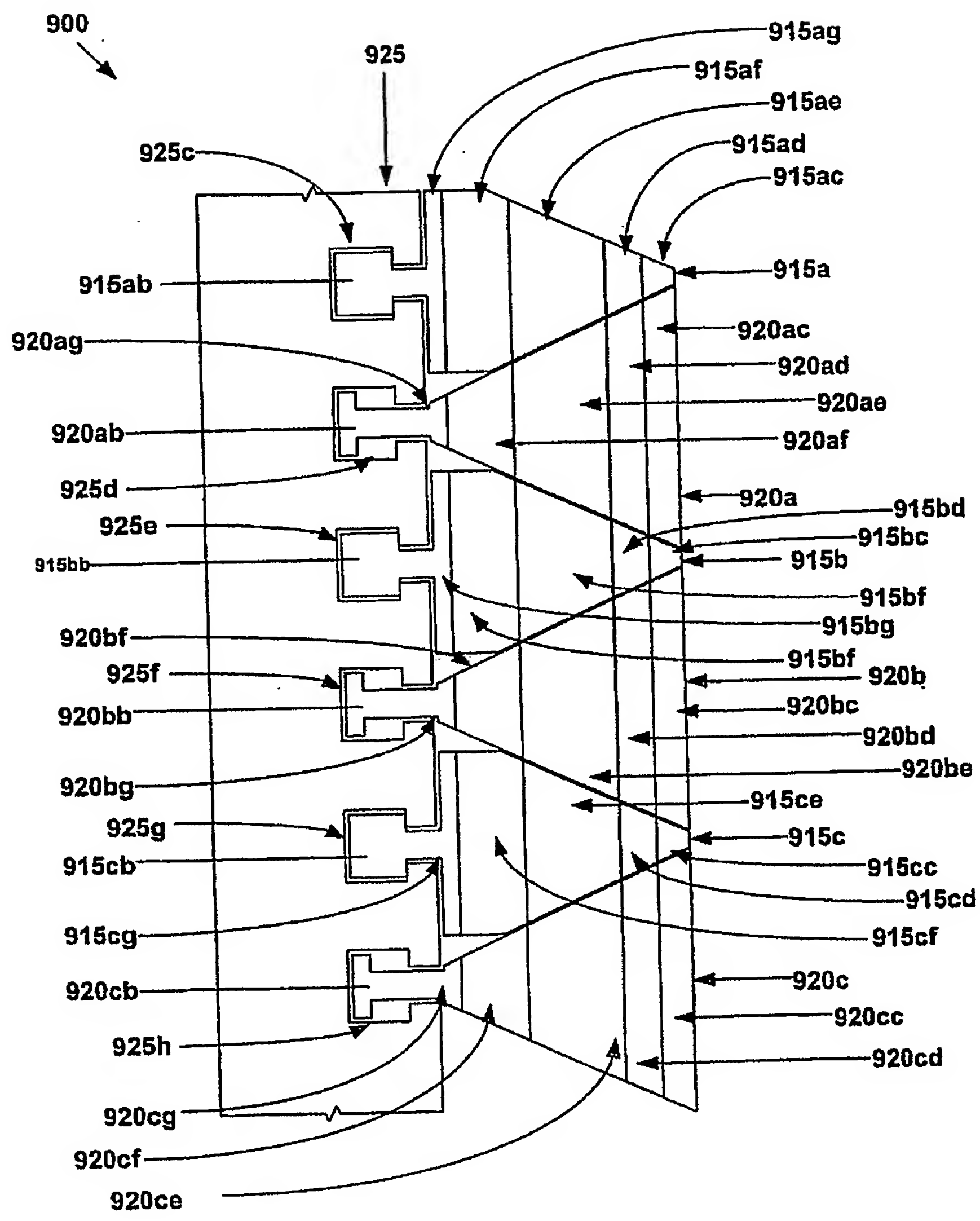
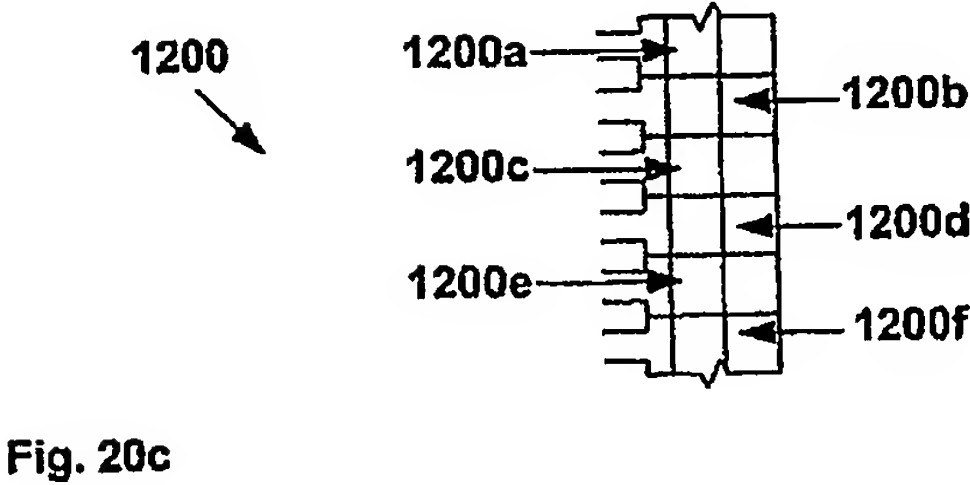
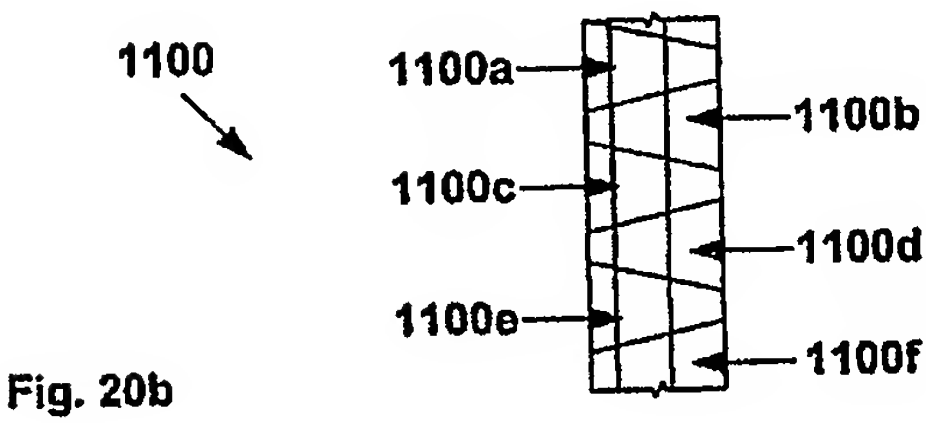
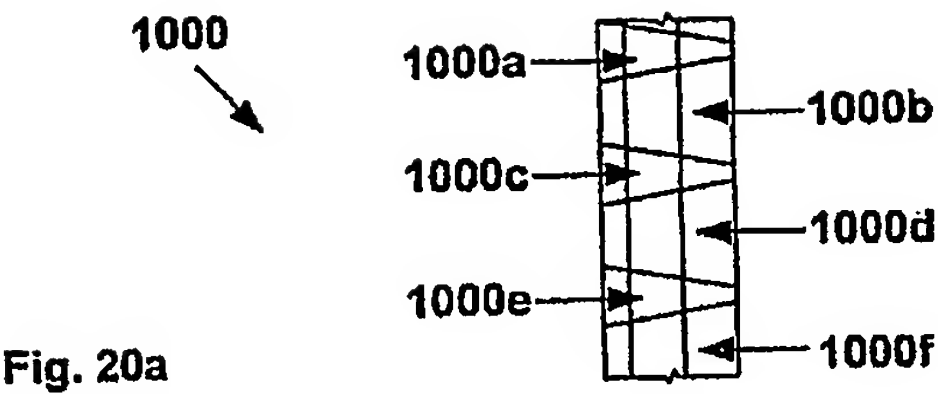


Fig. 19b

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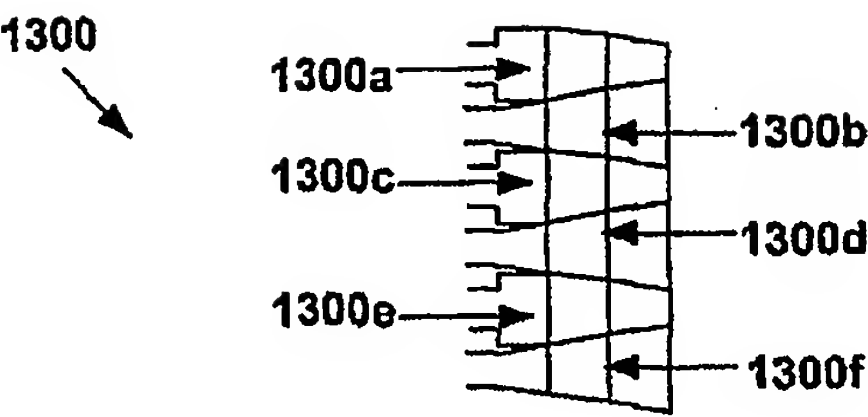


Fig. 20d

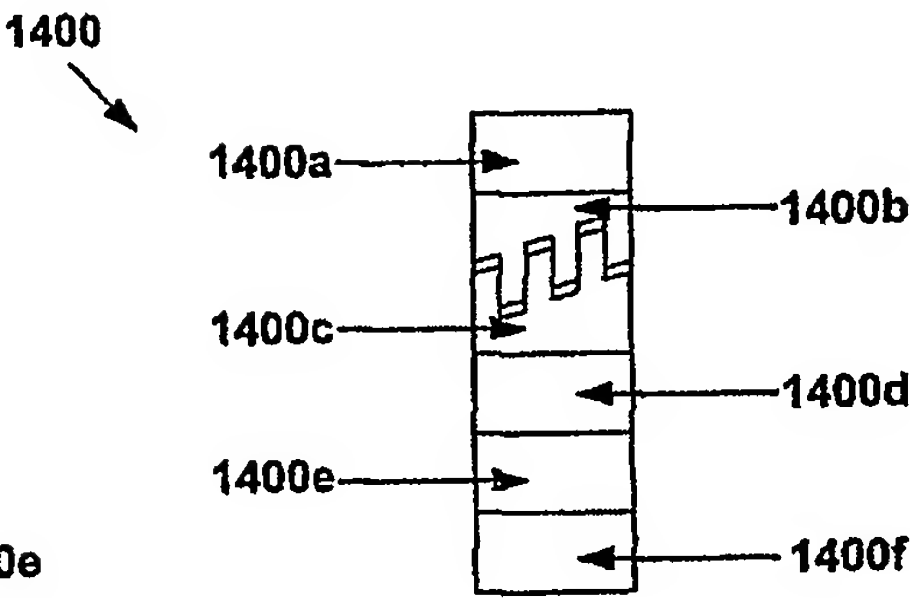


Fig. 20e

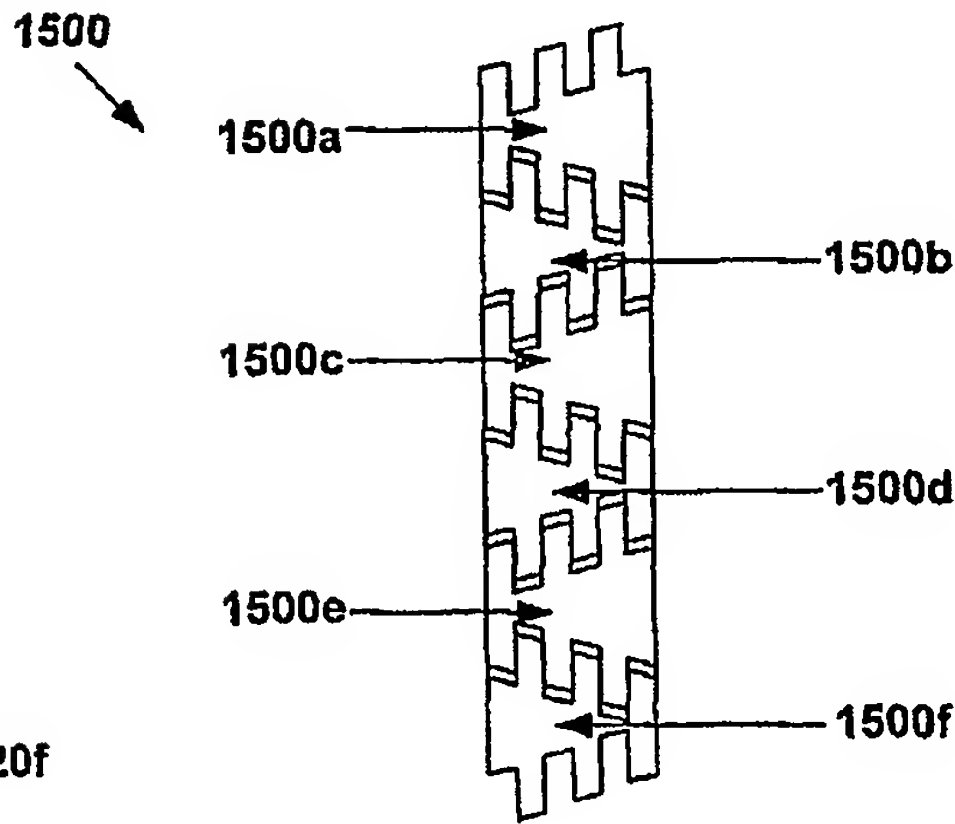
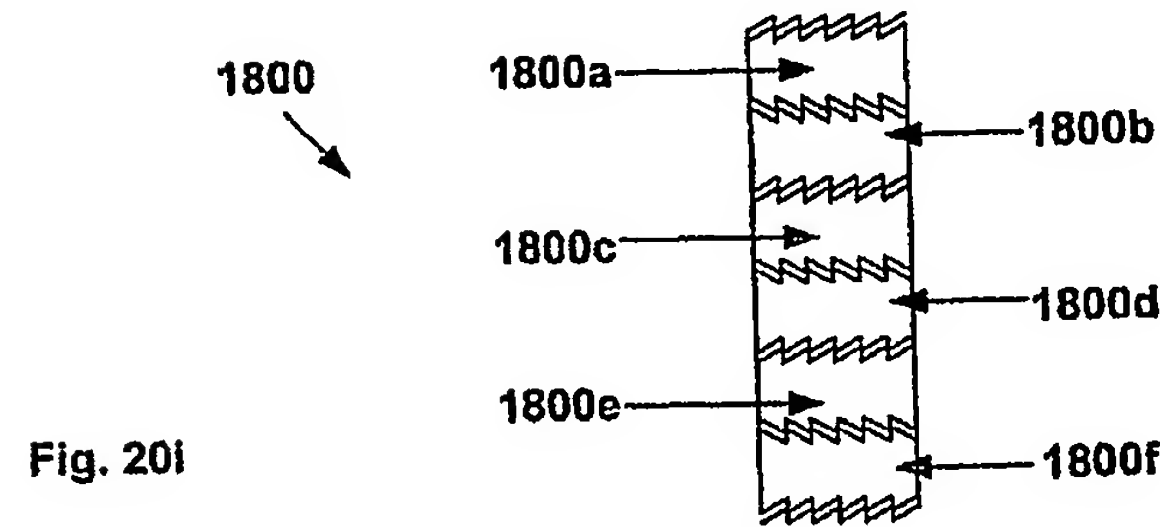
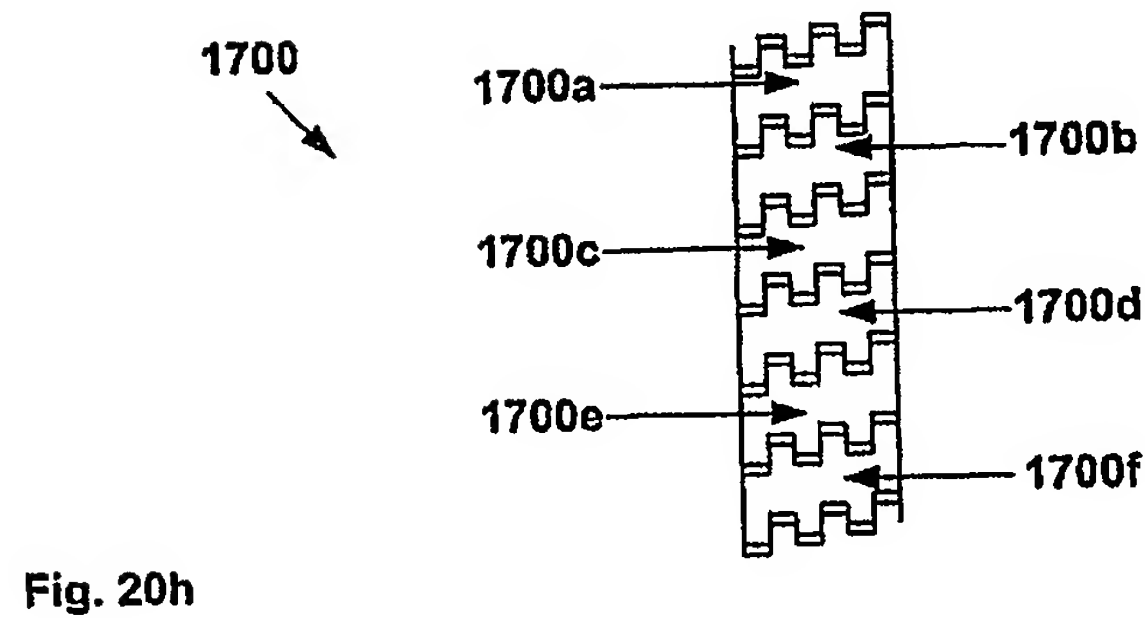
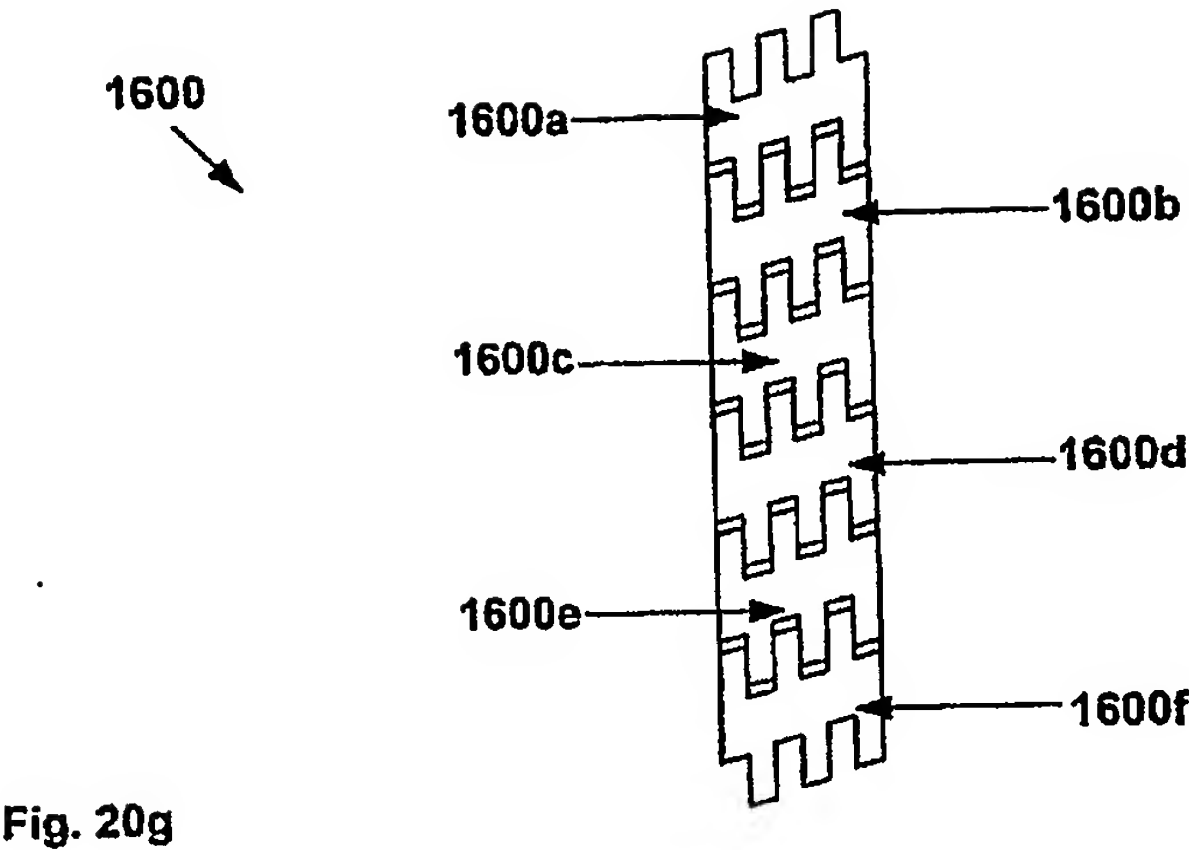
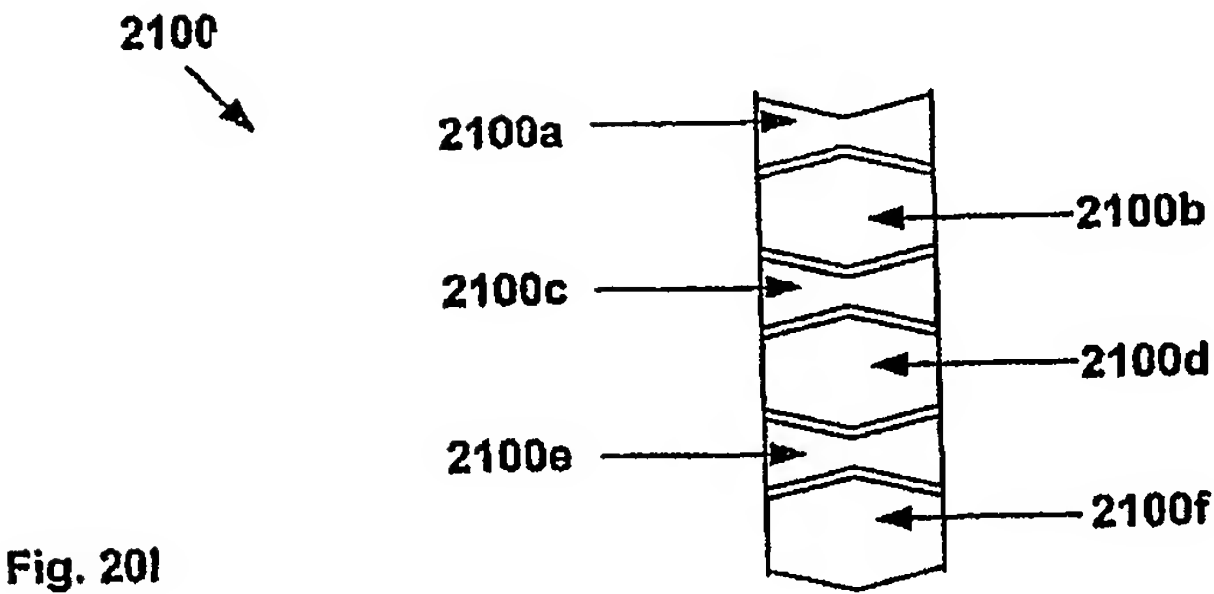
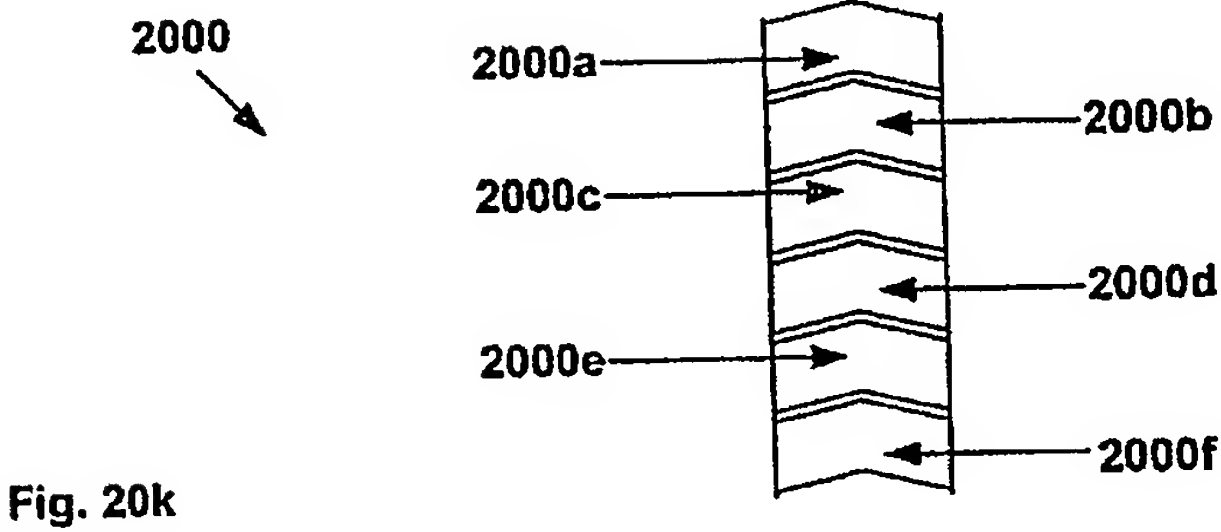
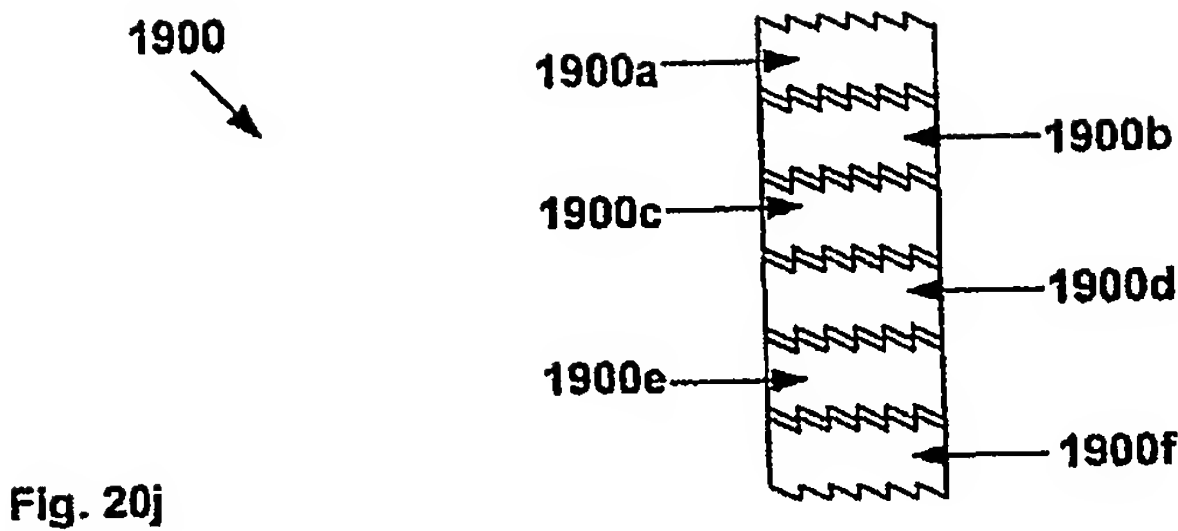
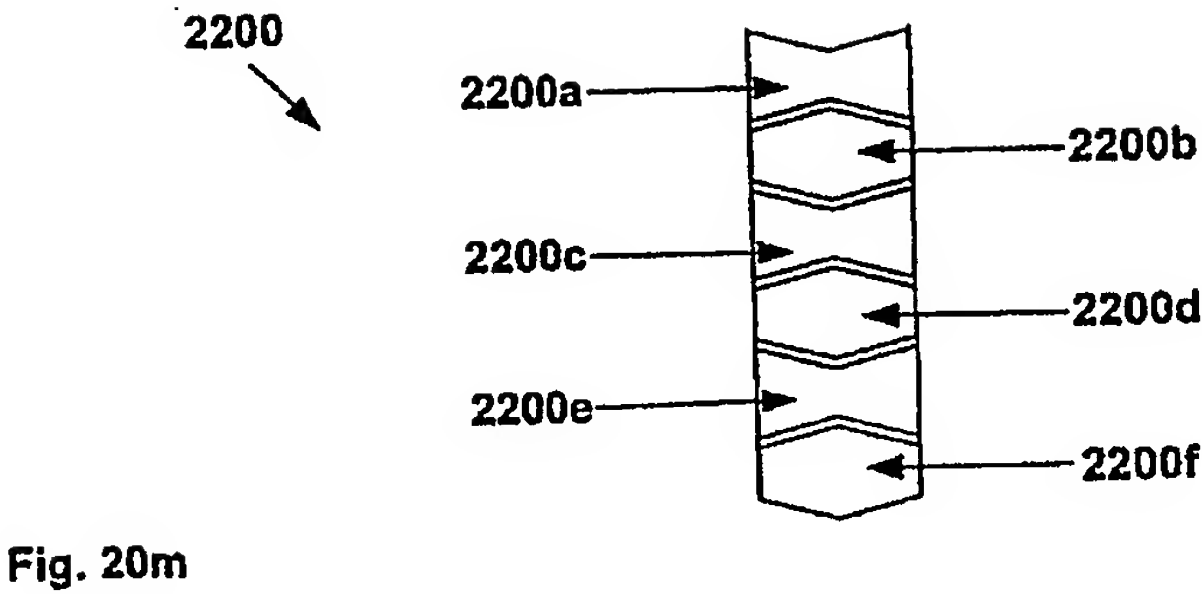


Fig. 20f









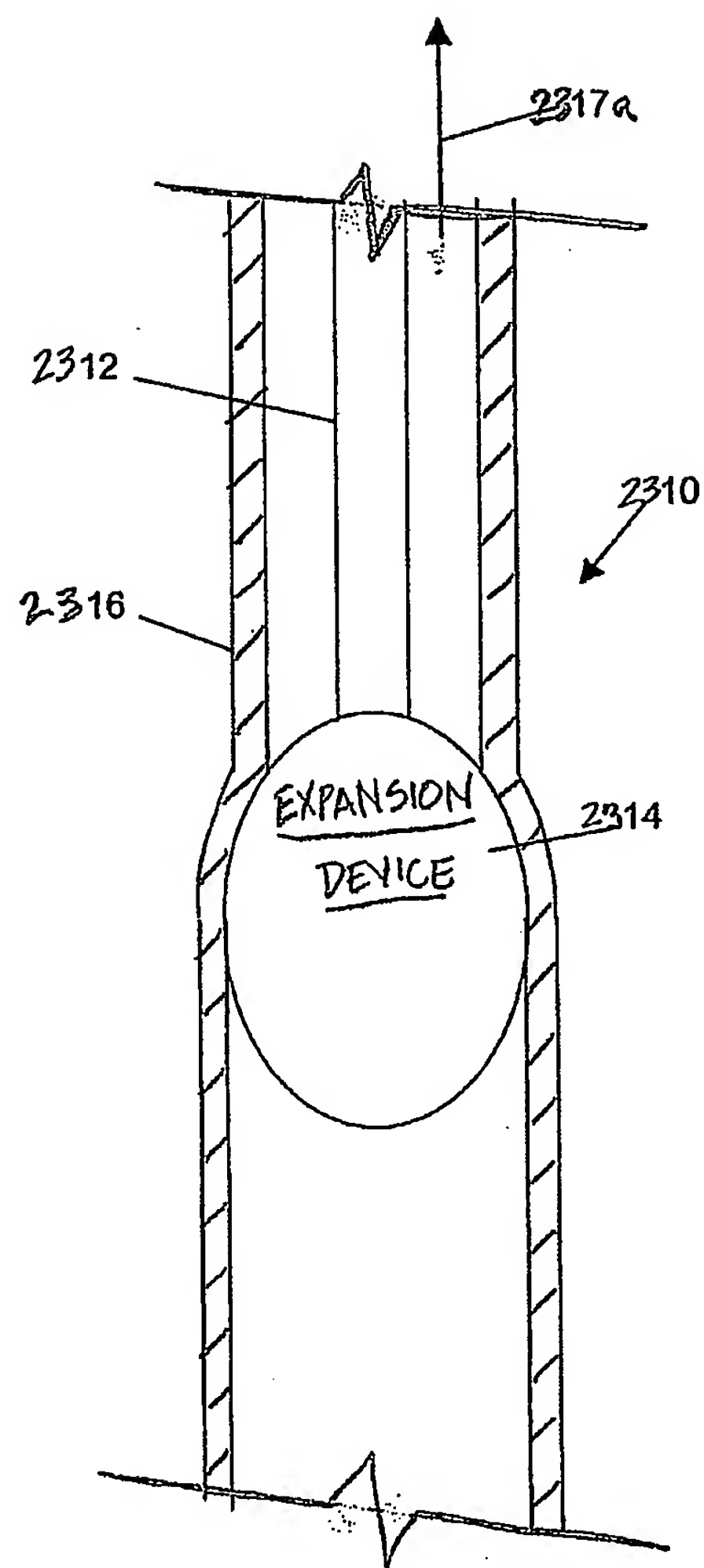


Fig.21a

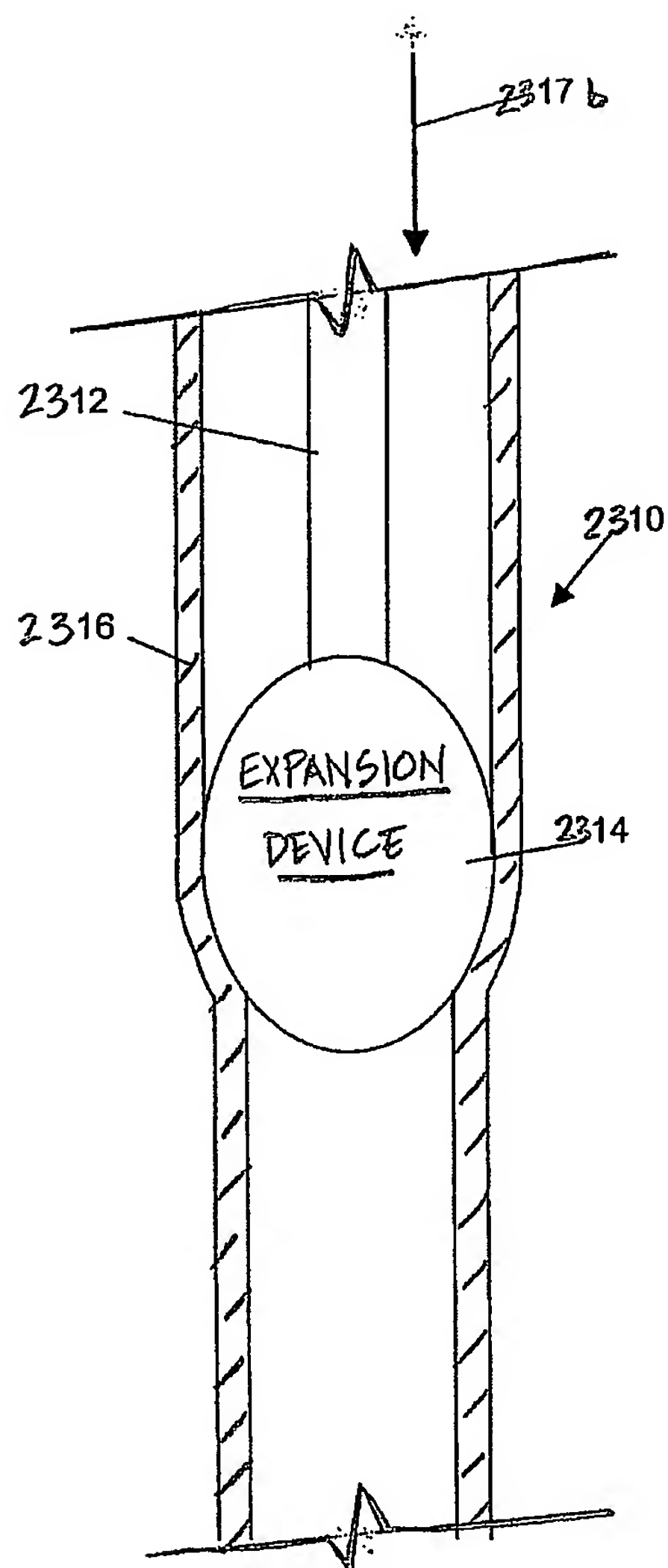


Fig.21b

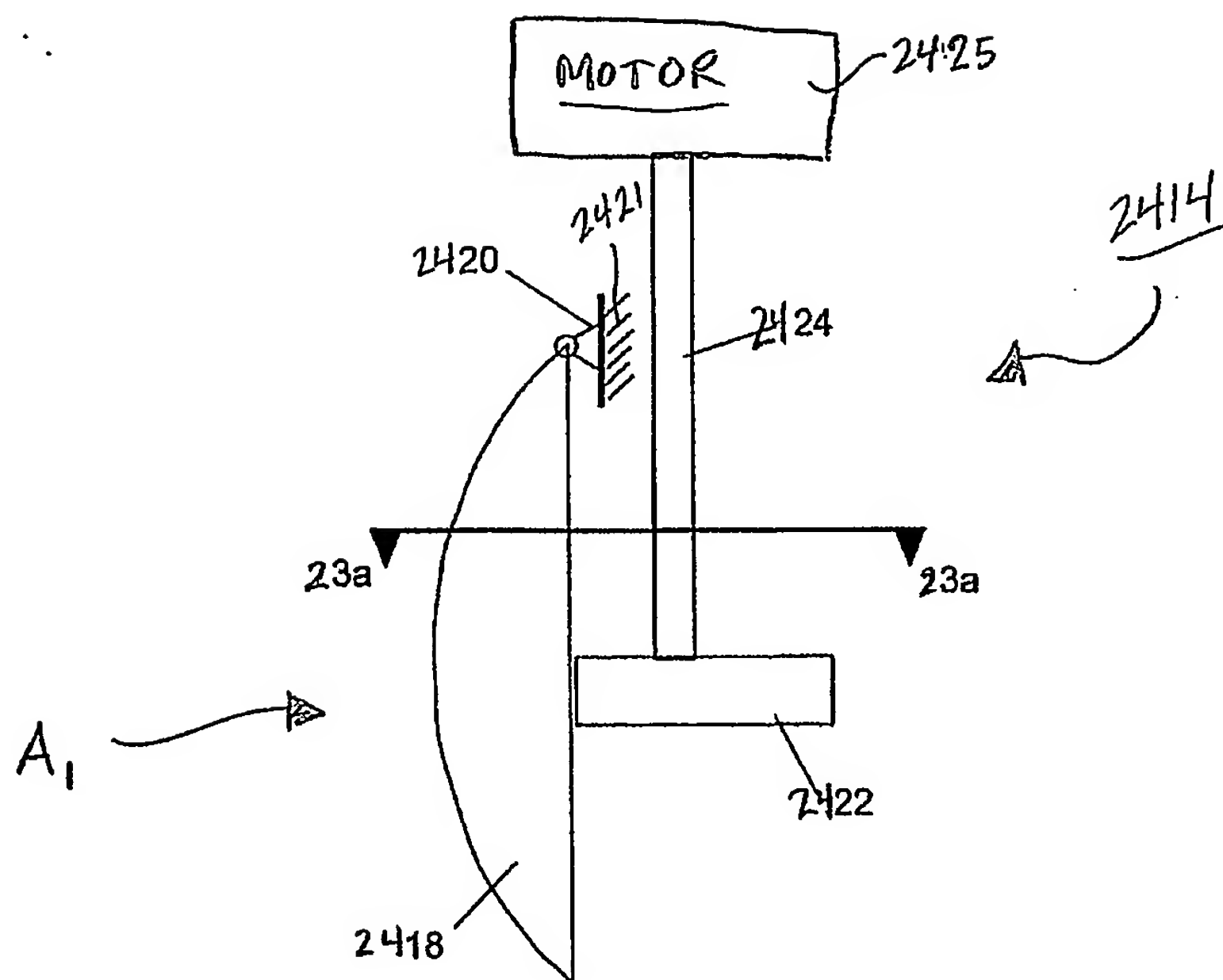


Fig. 22a

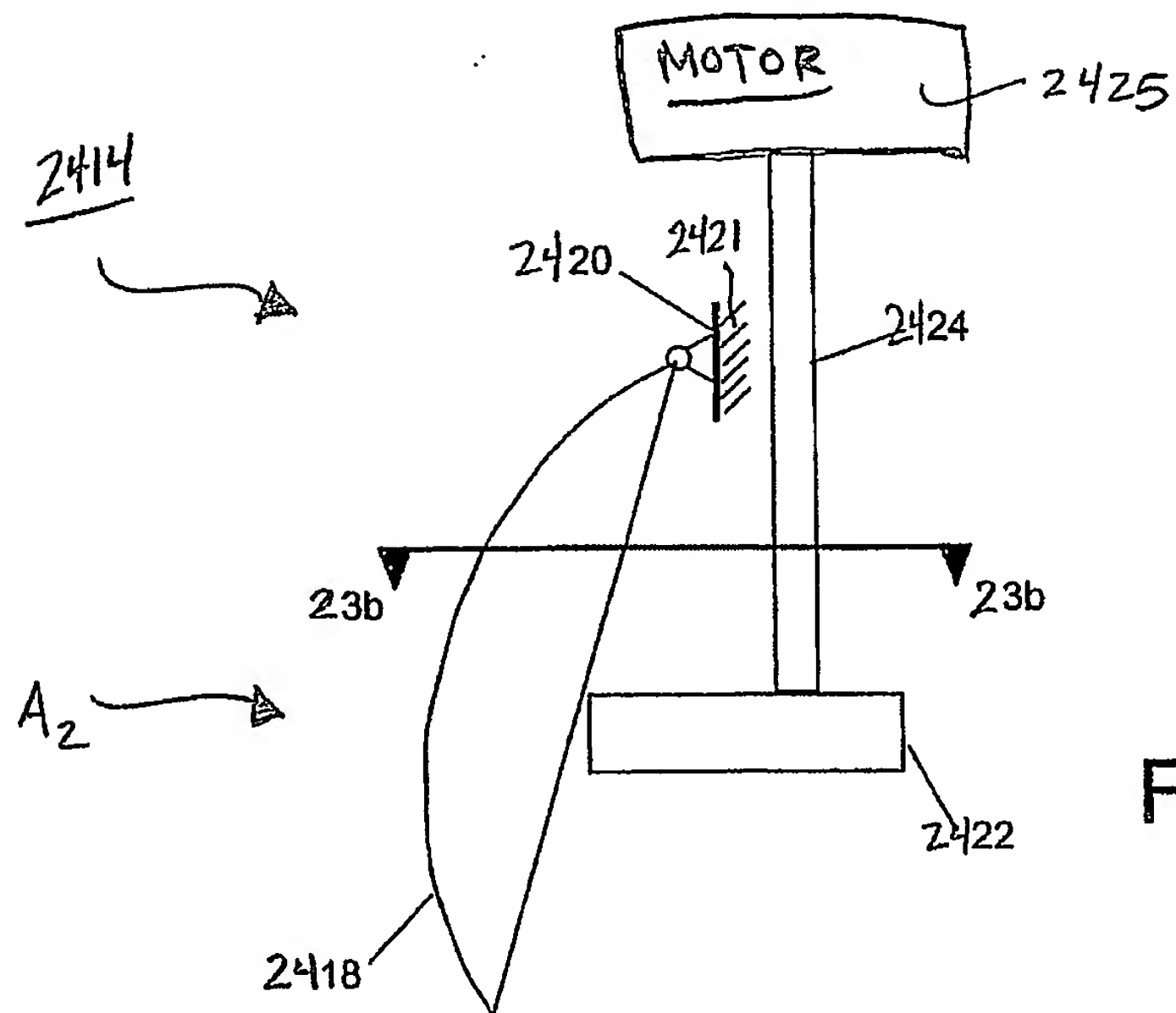


Fig. 22b

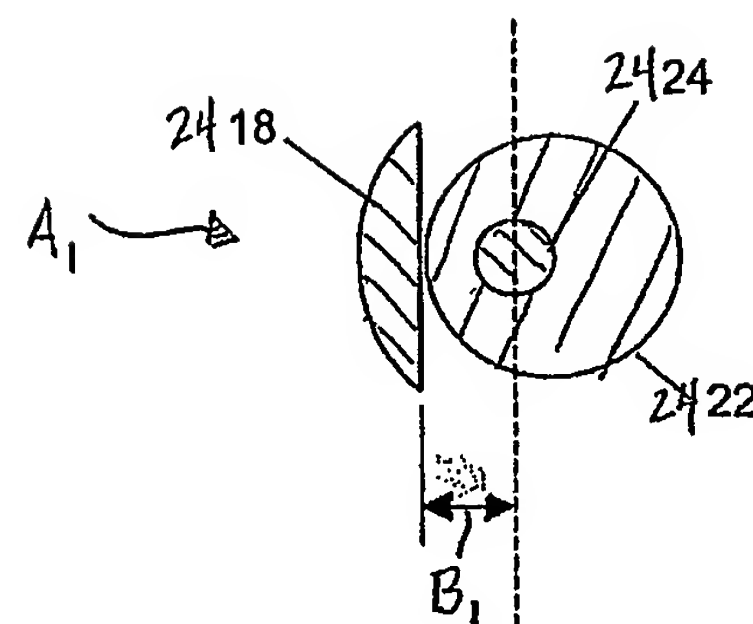


Fig.23a

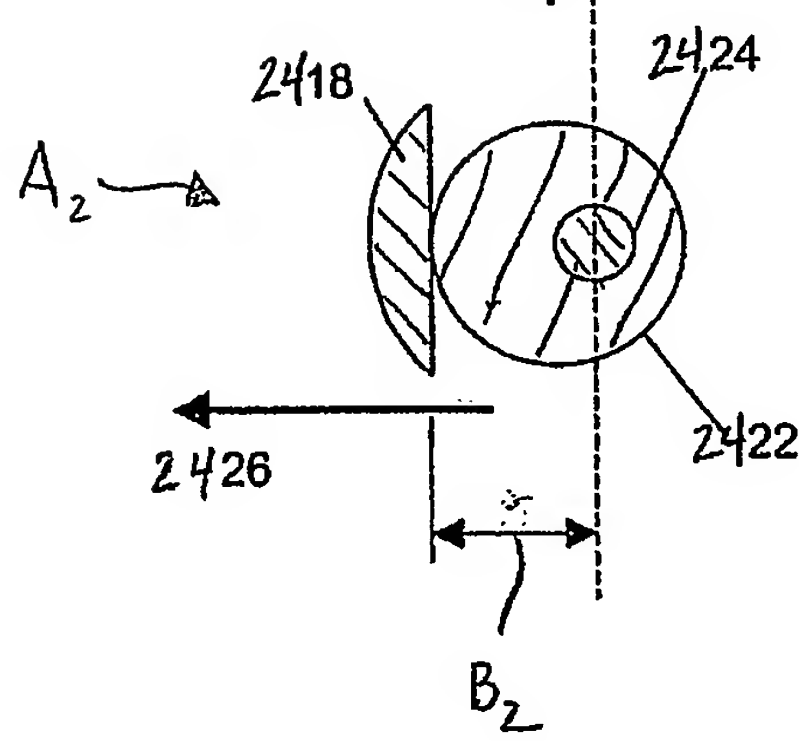


Fig.23b



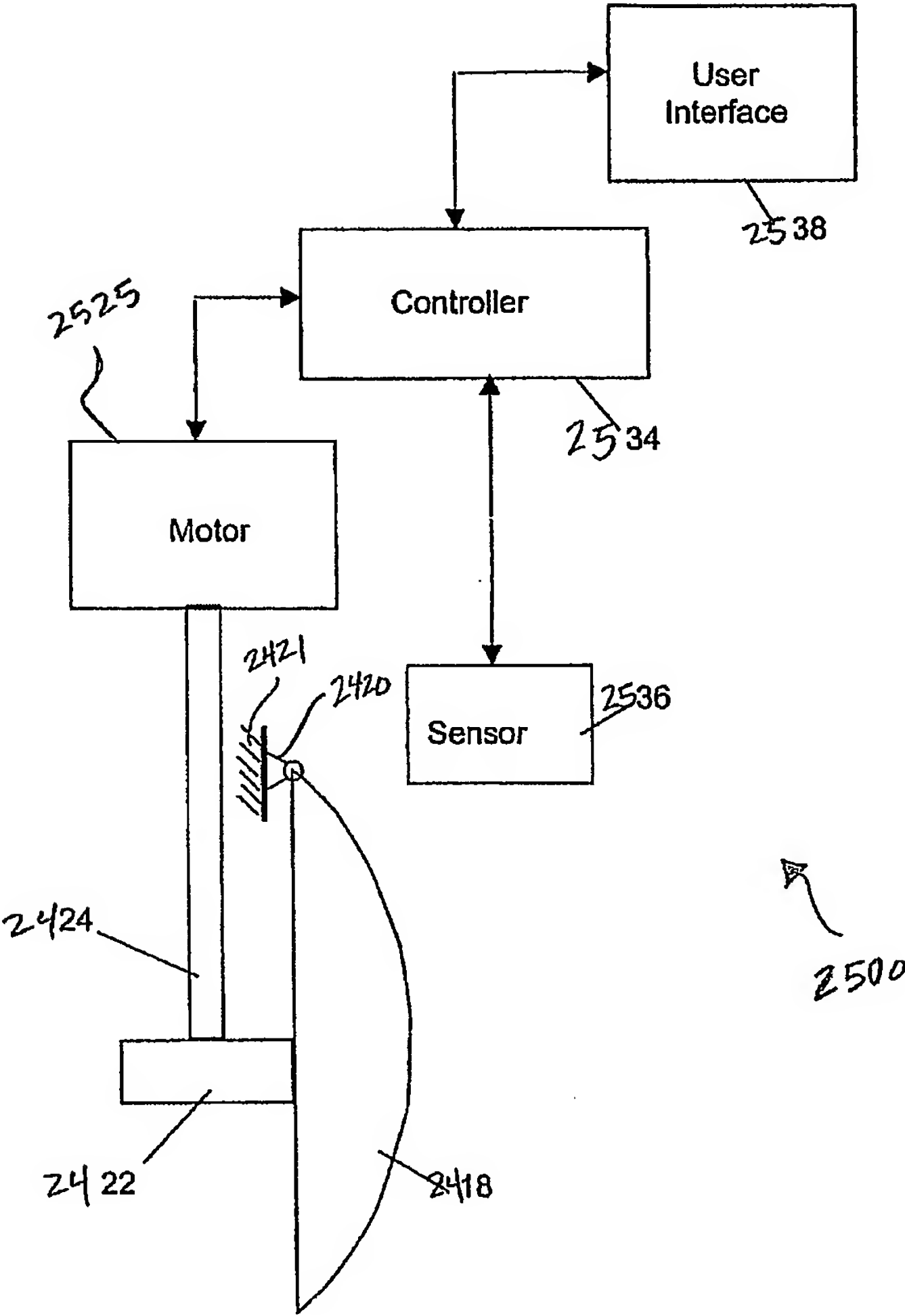


Fig.24

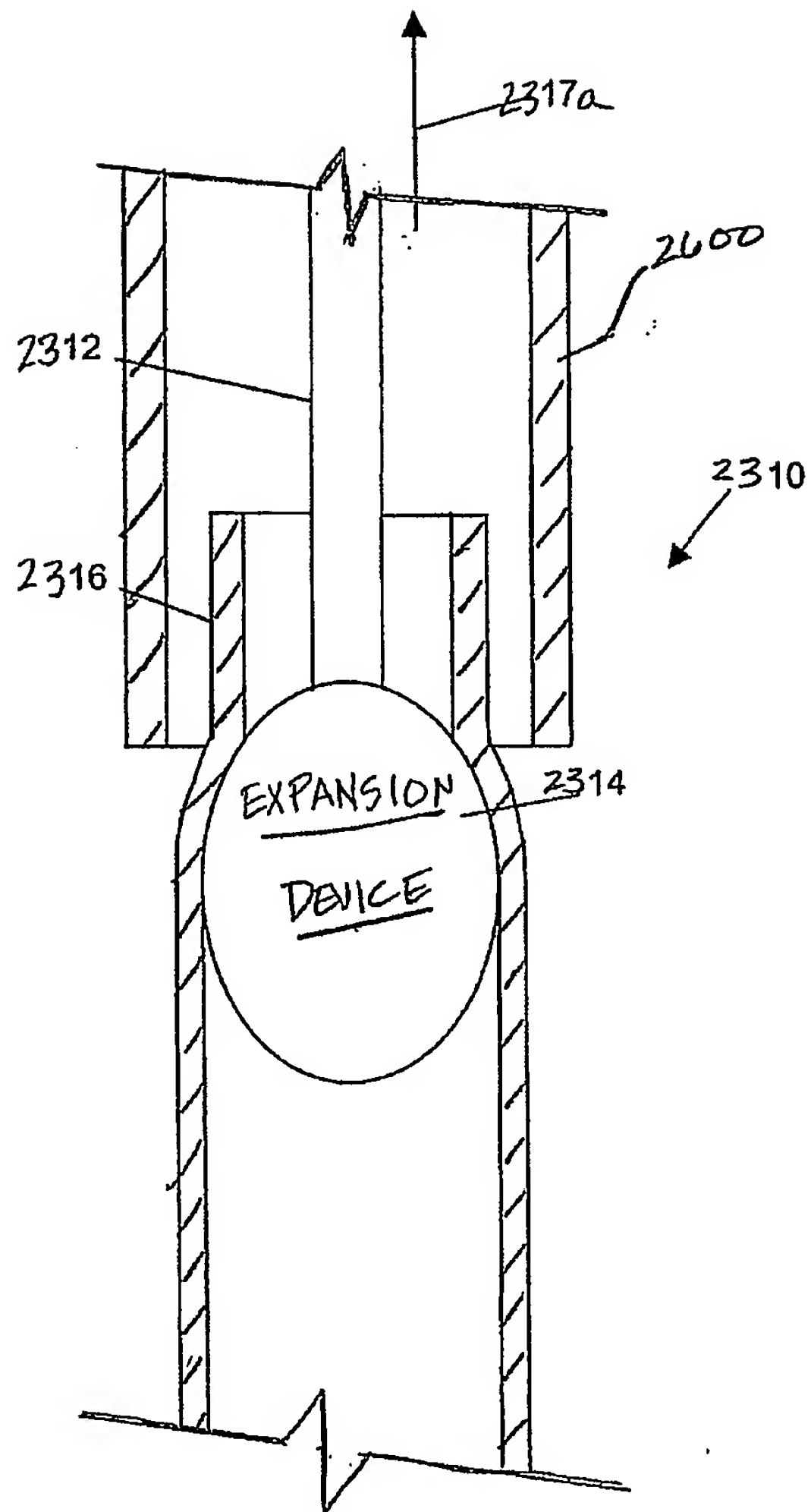


Fig.25a

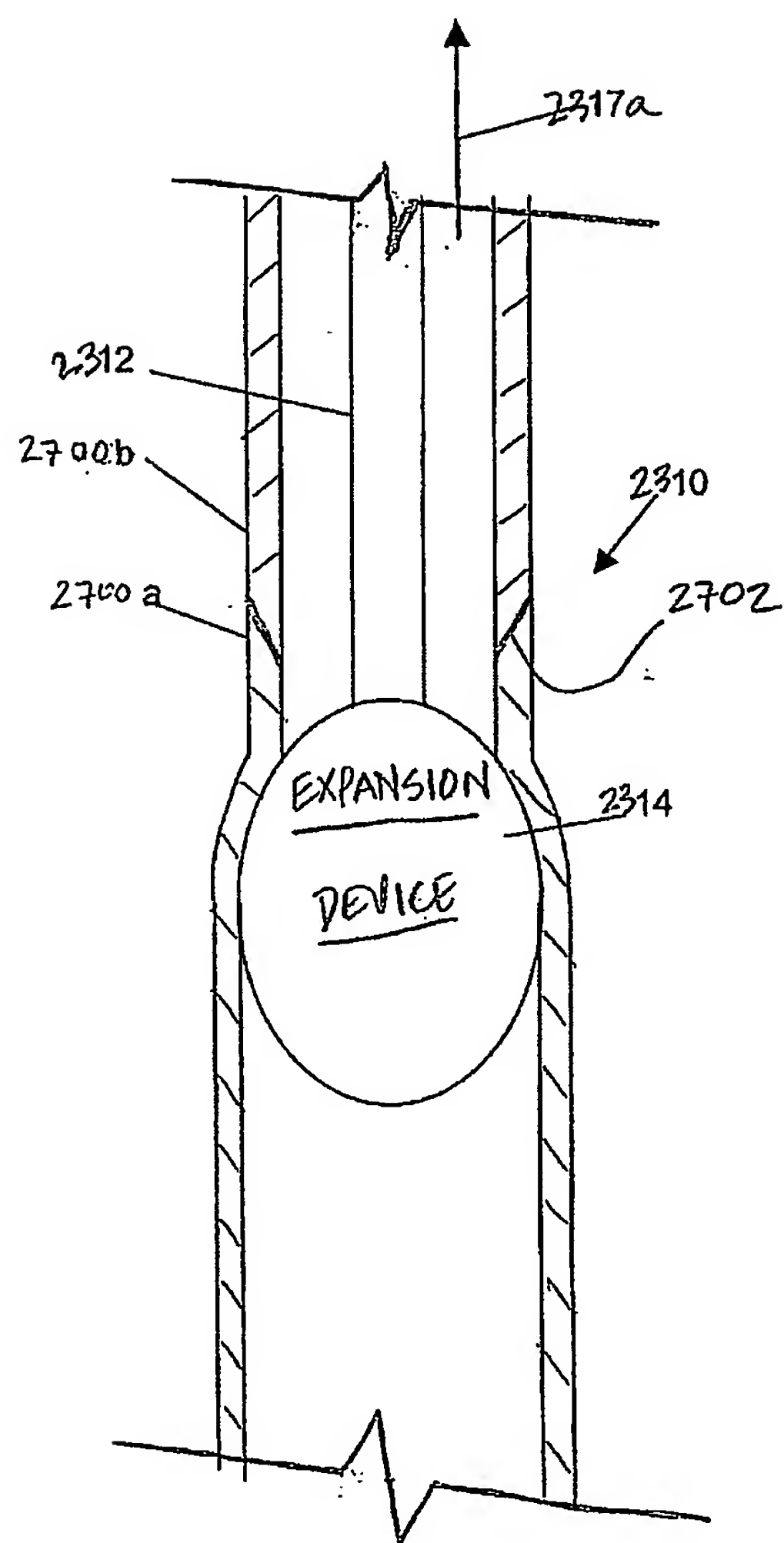


Fig.25b

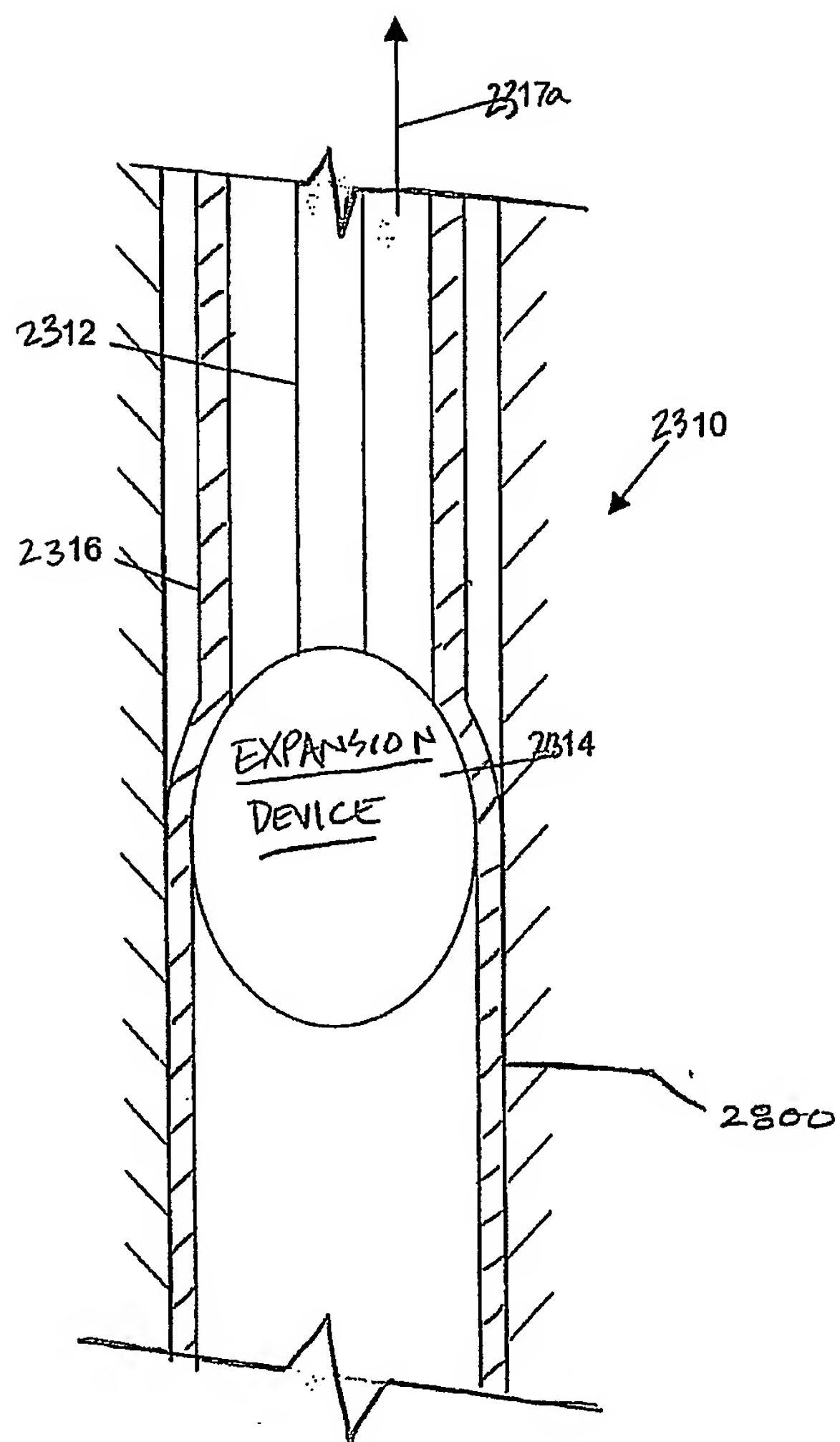
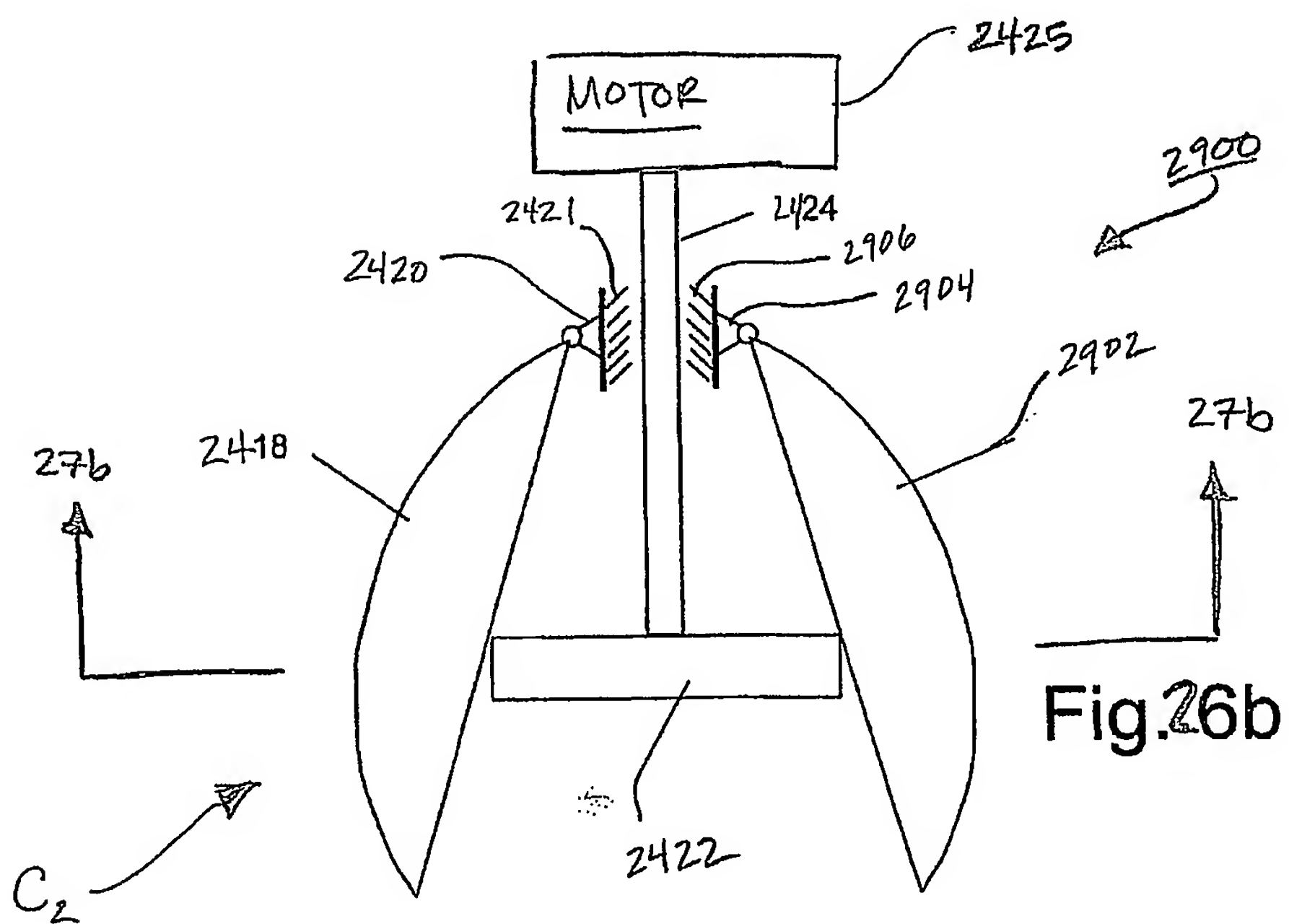
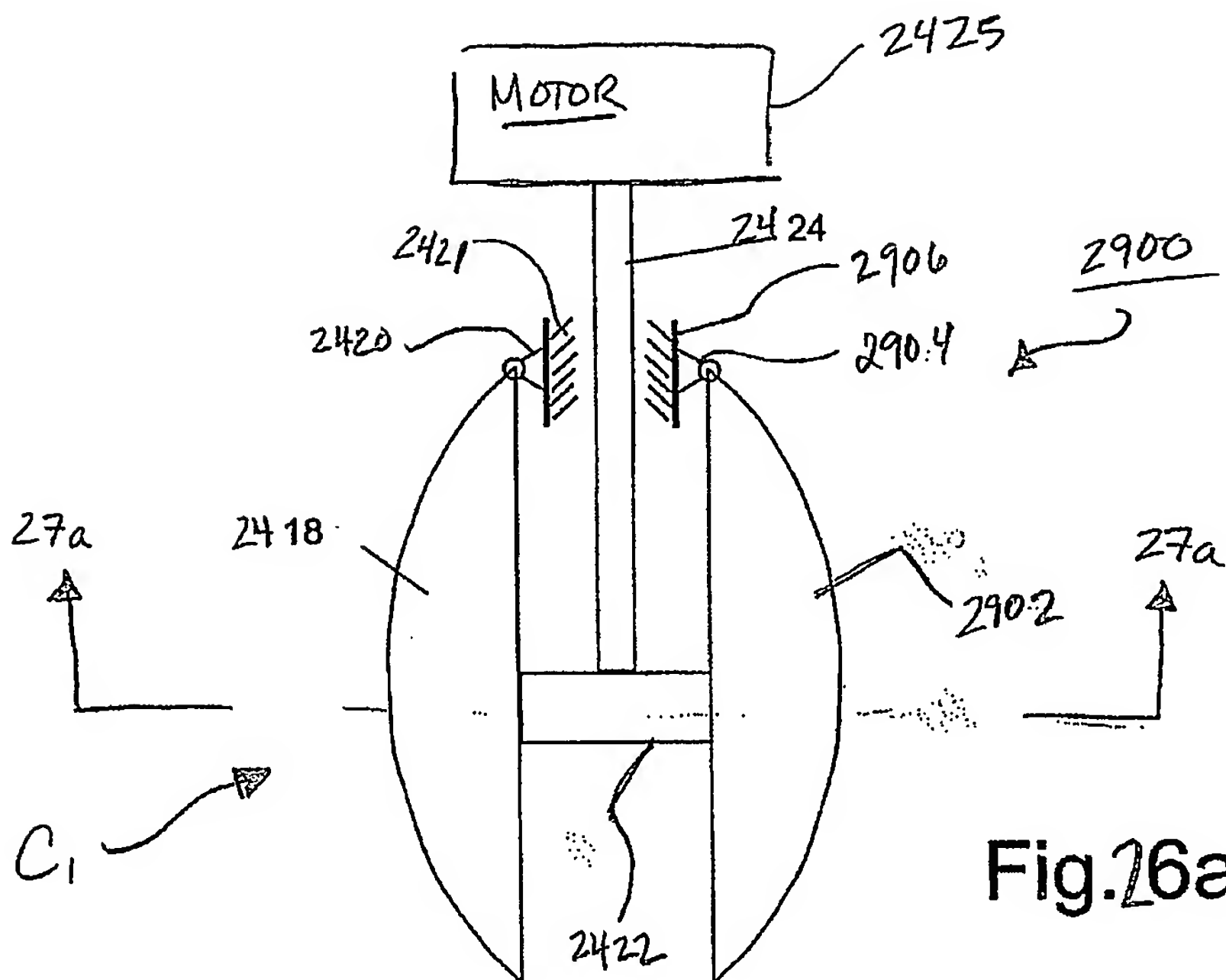
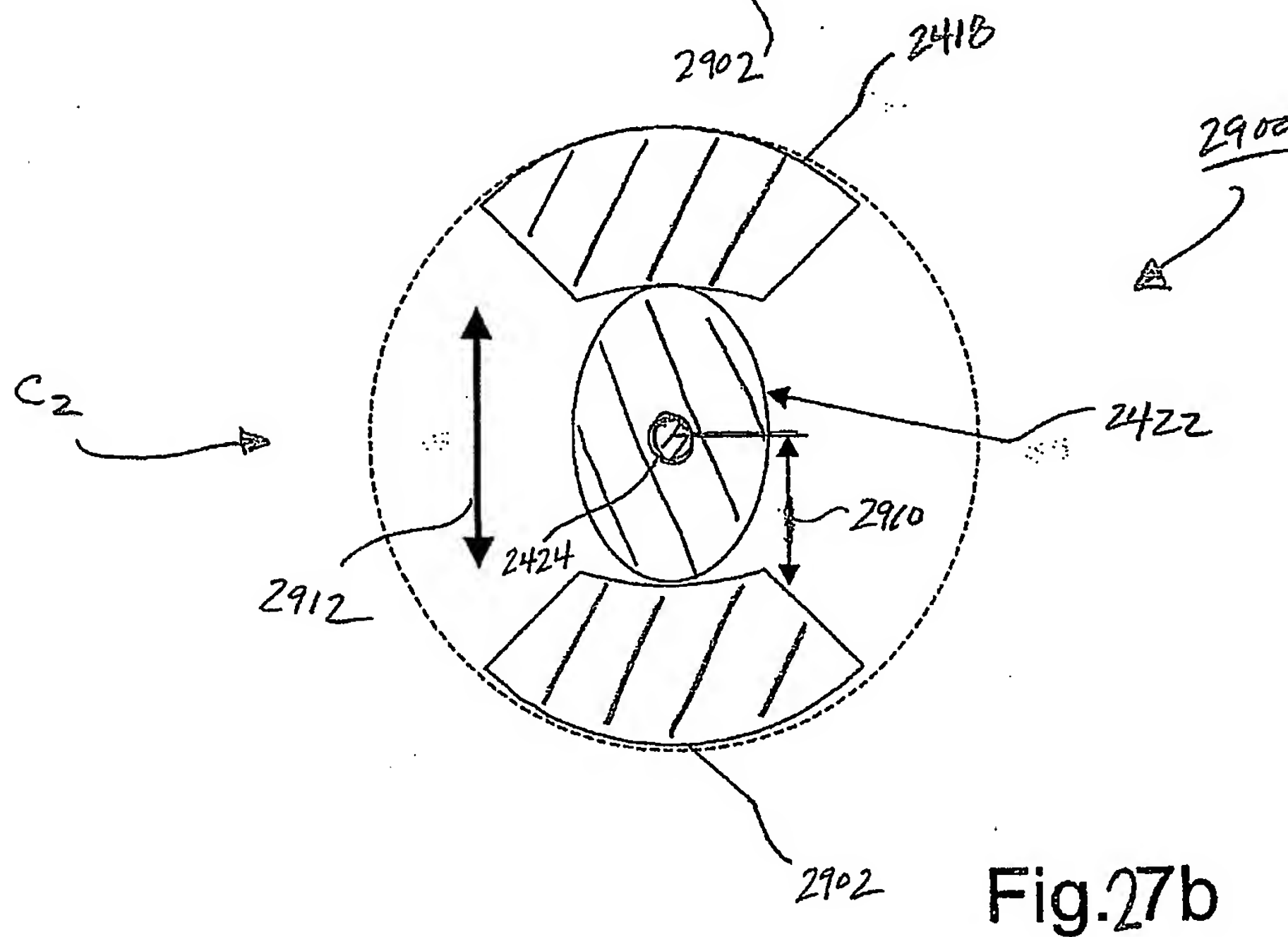
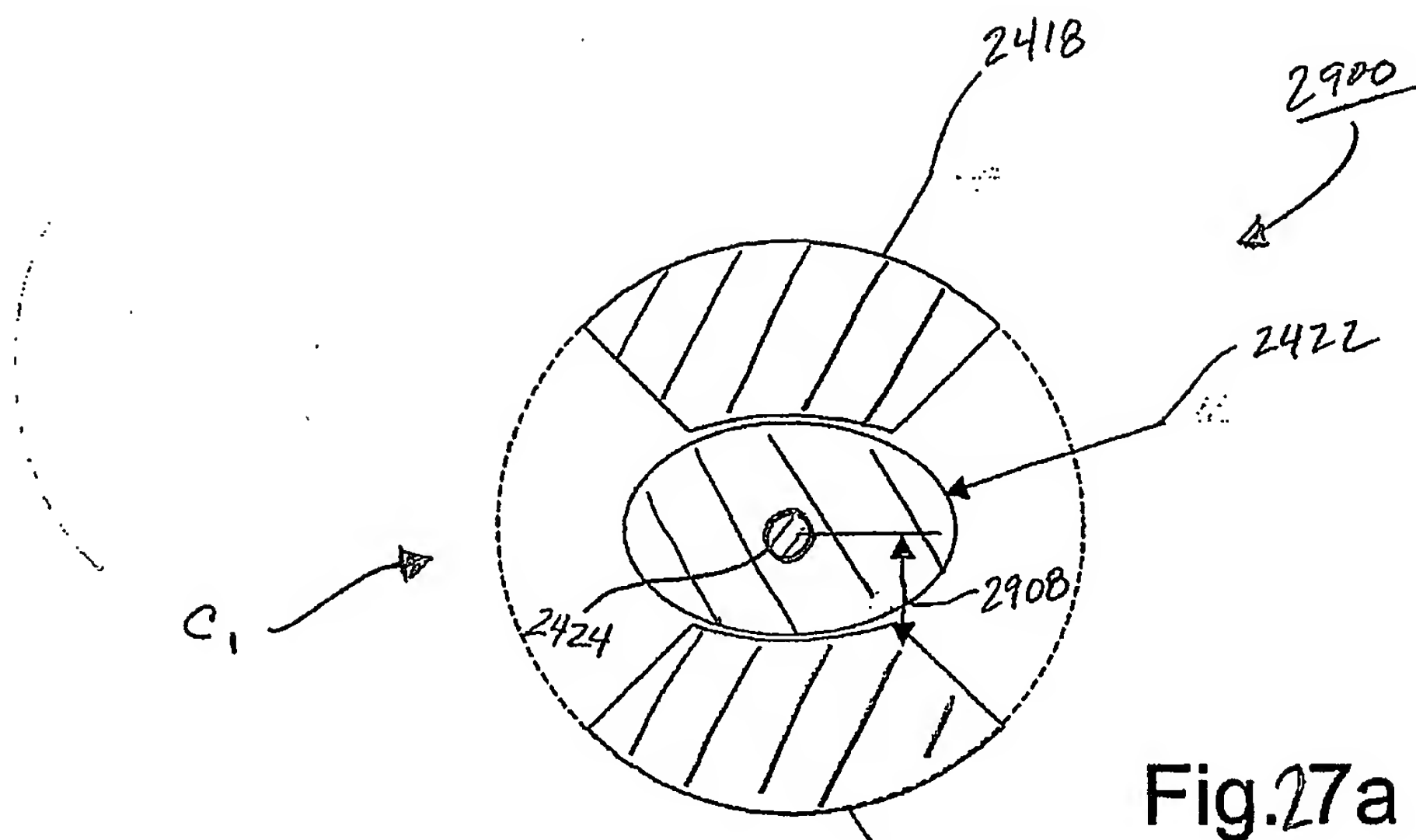


Fig.25c





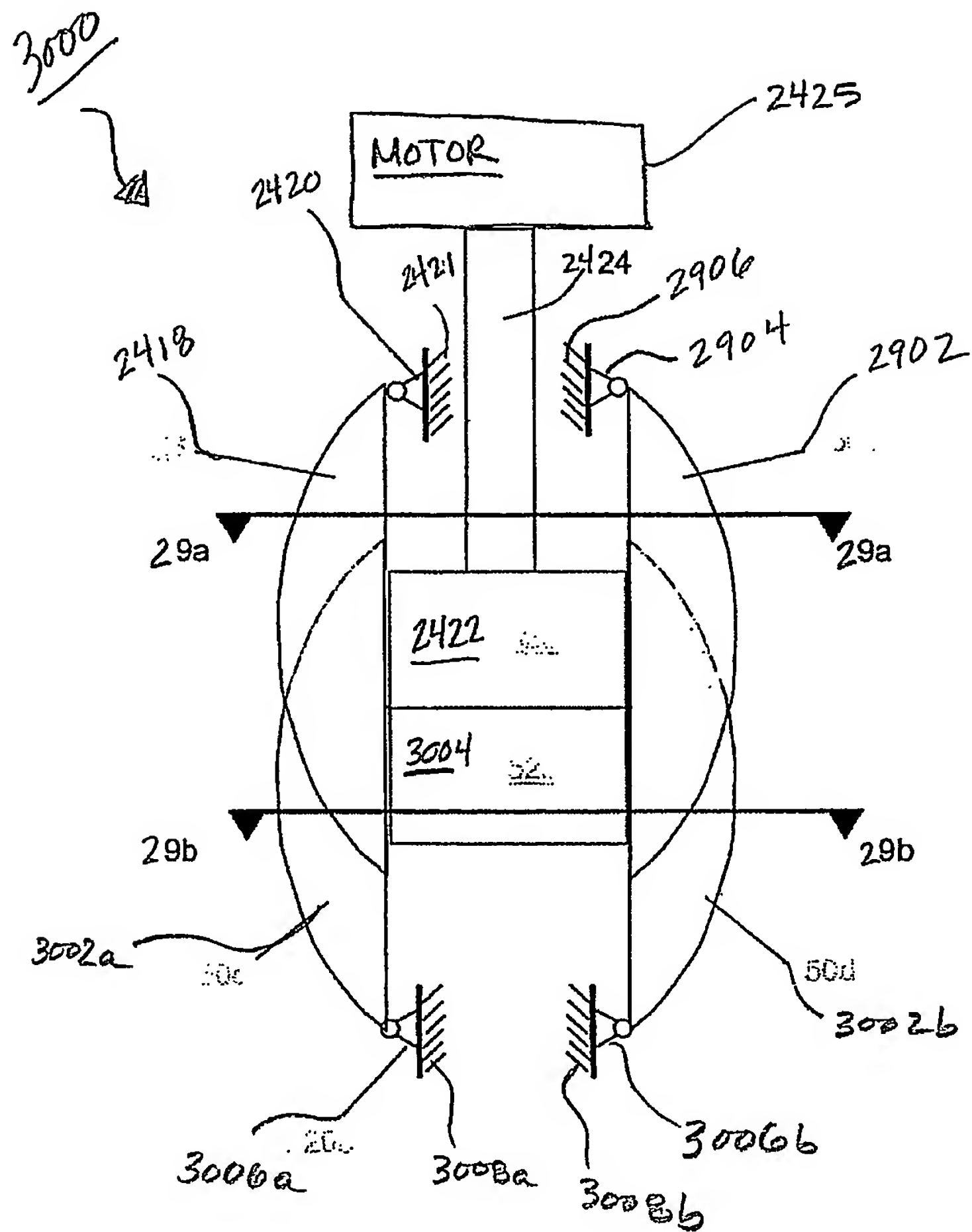


Fig.28



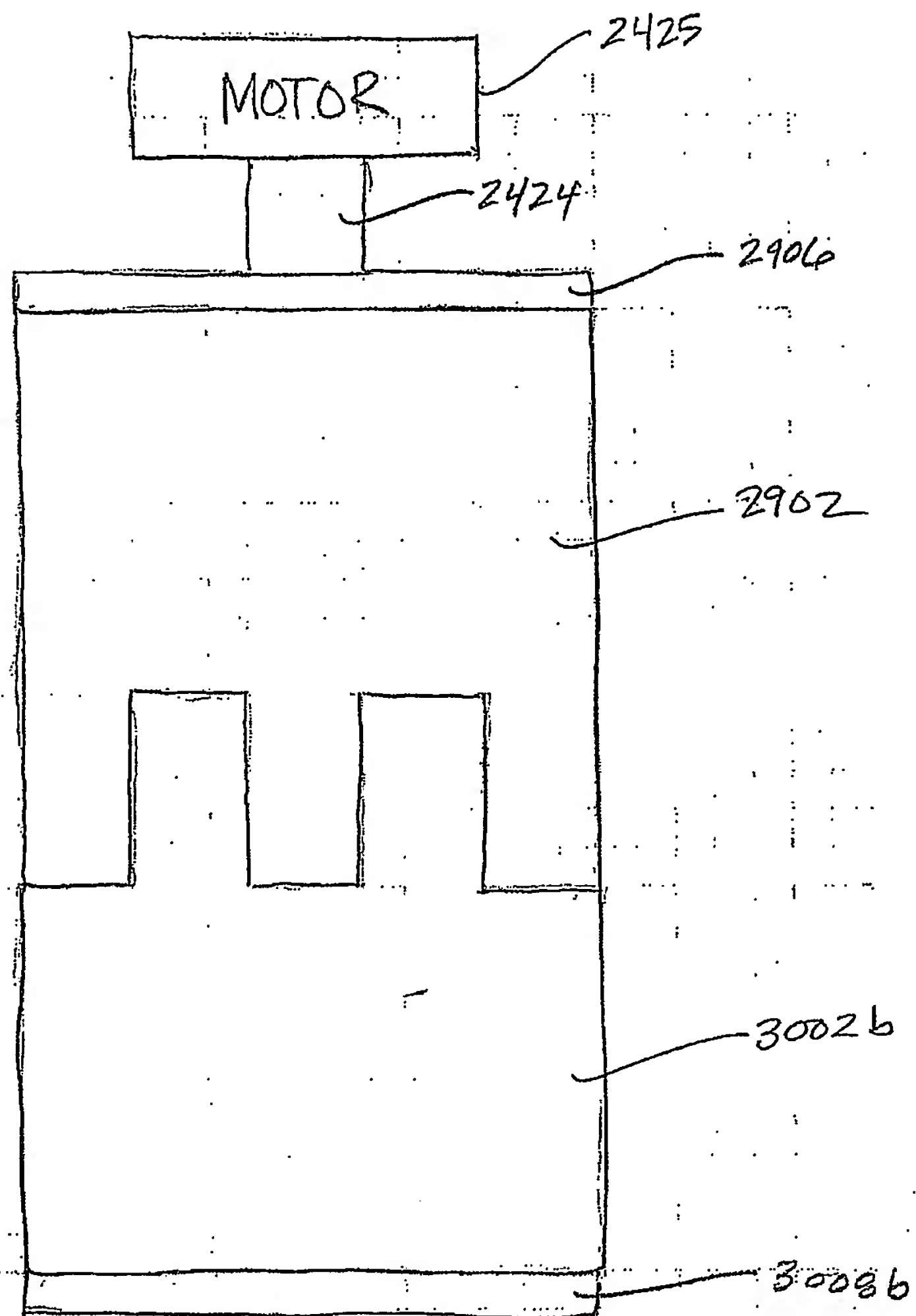


FIGURE 28a

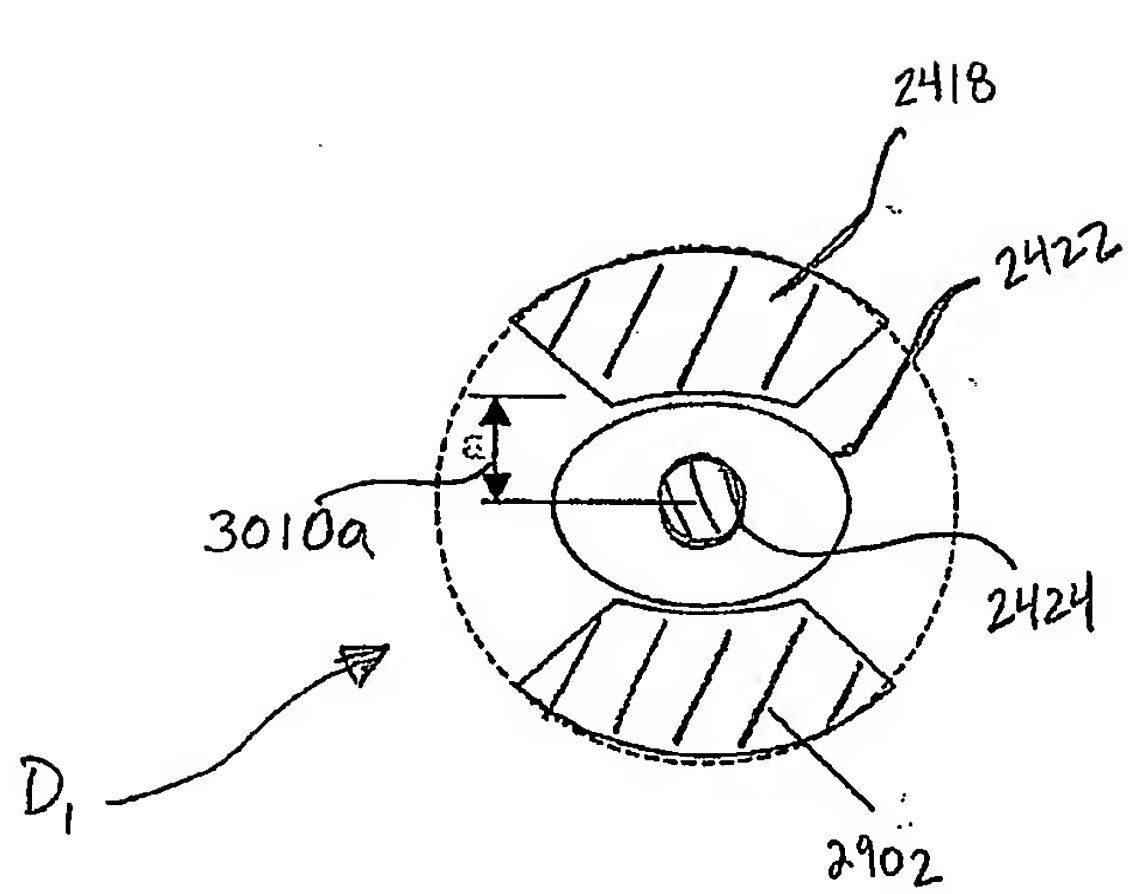


Fig. 29a

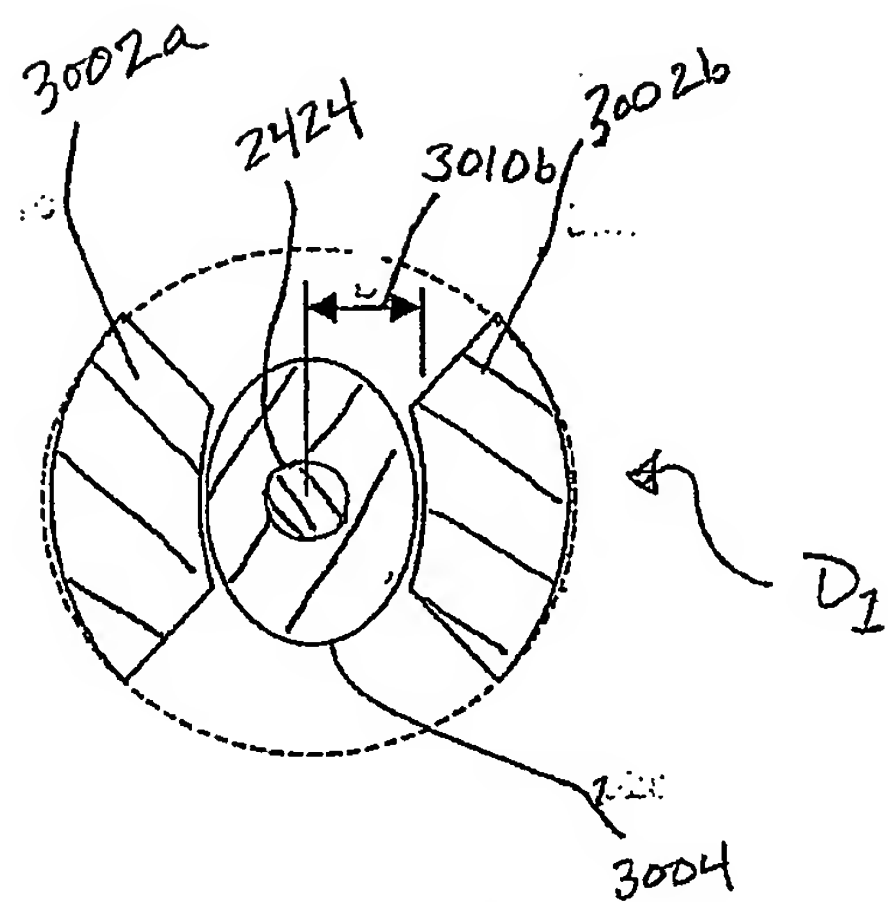


Fig. 29b

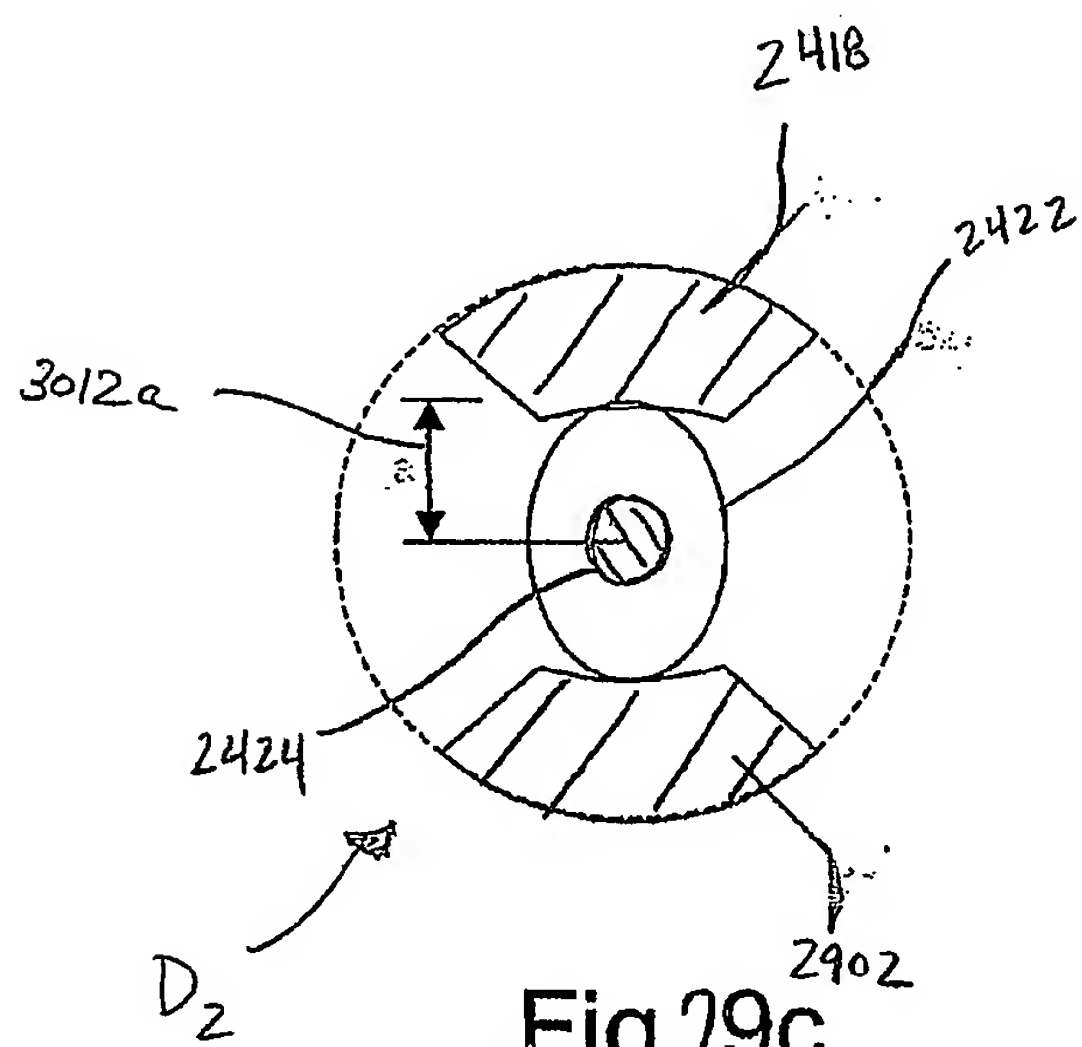


Fig. 29c

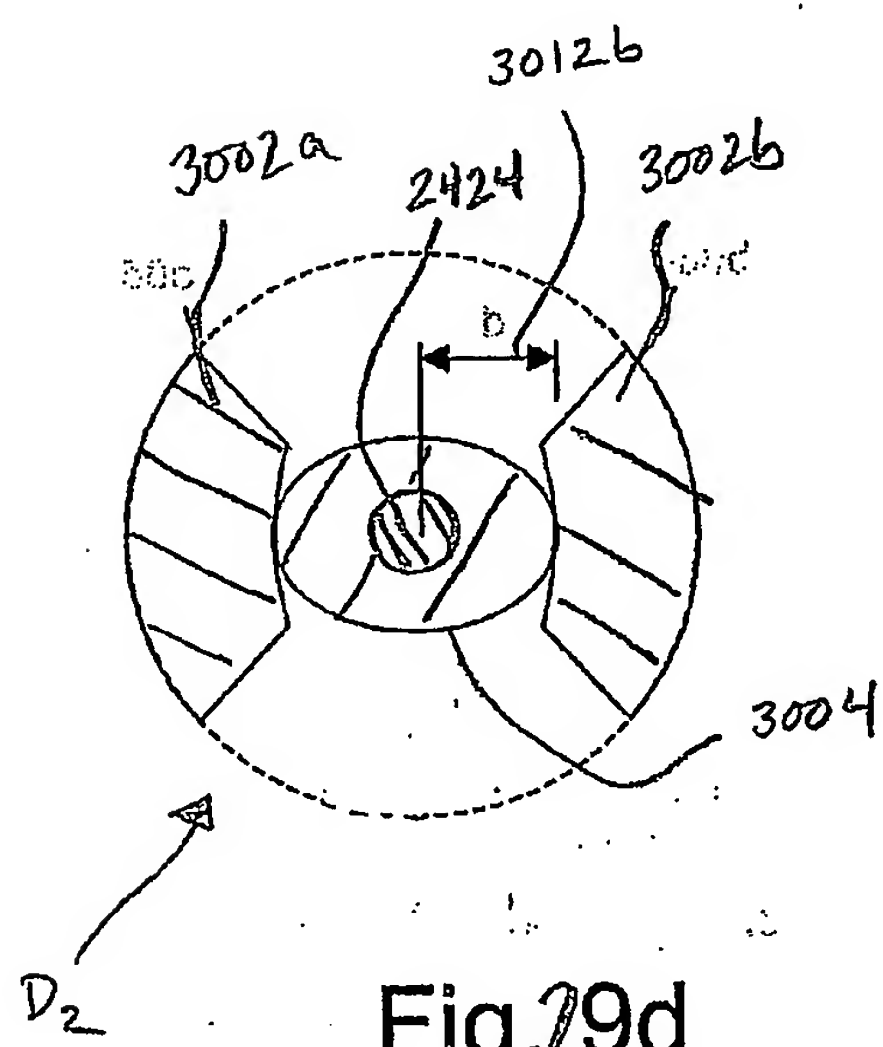


Fig. 29d

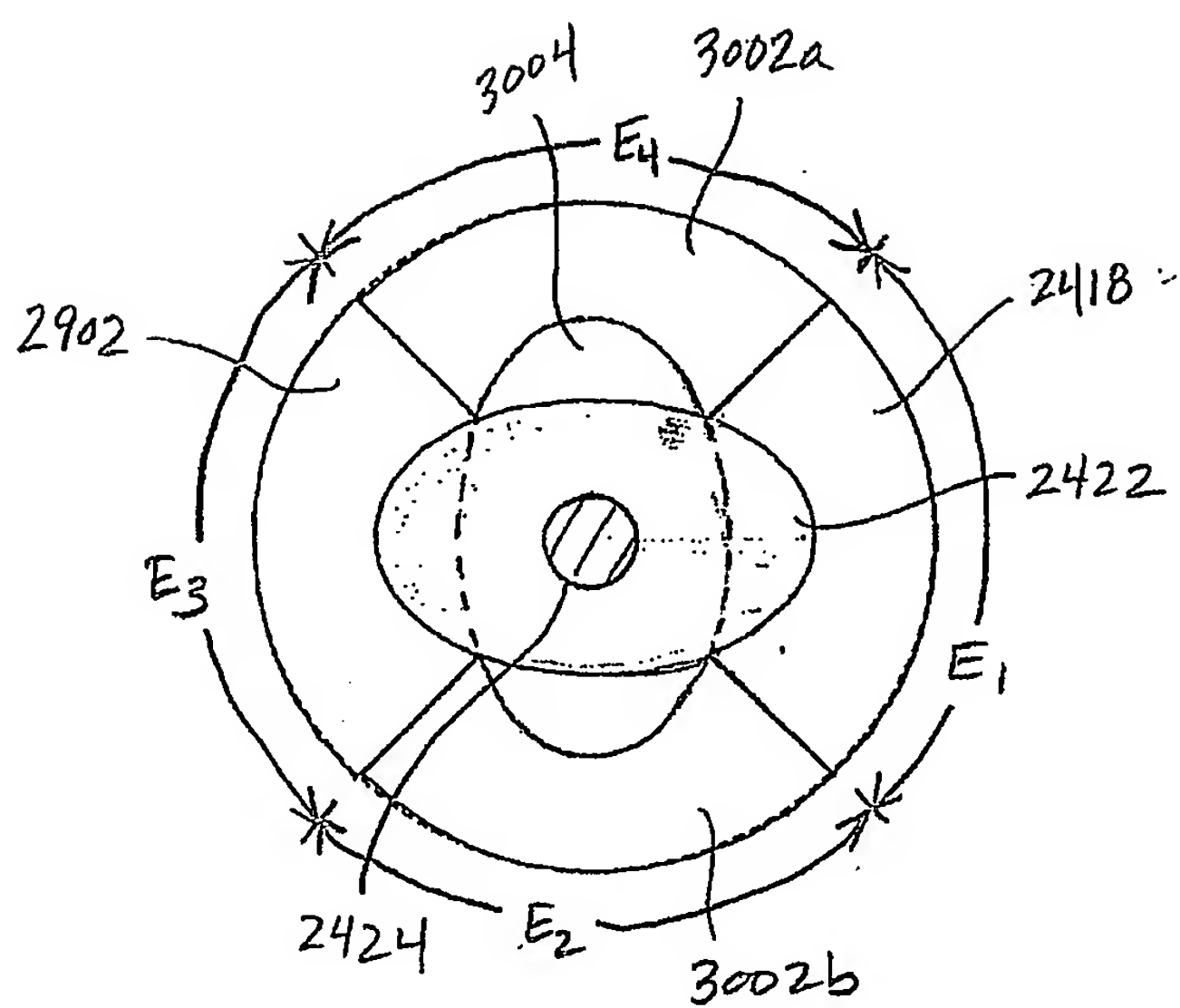


Fig.29e

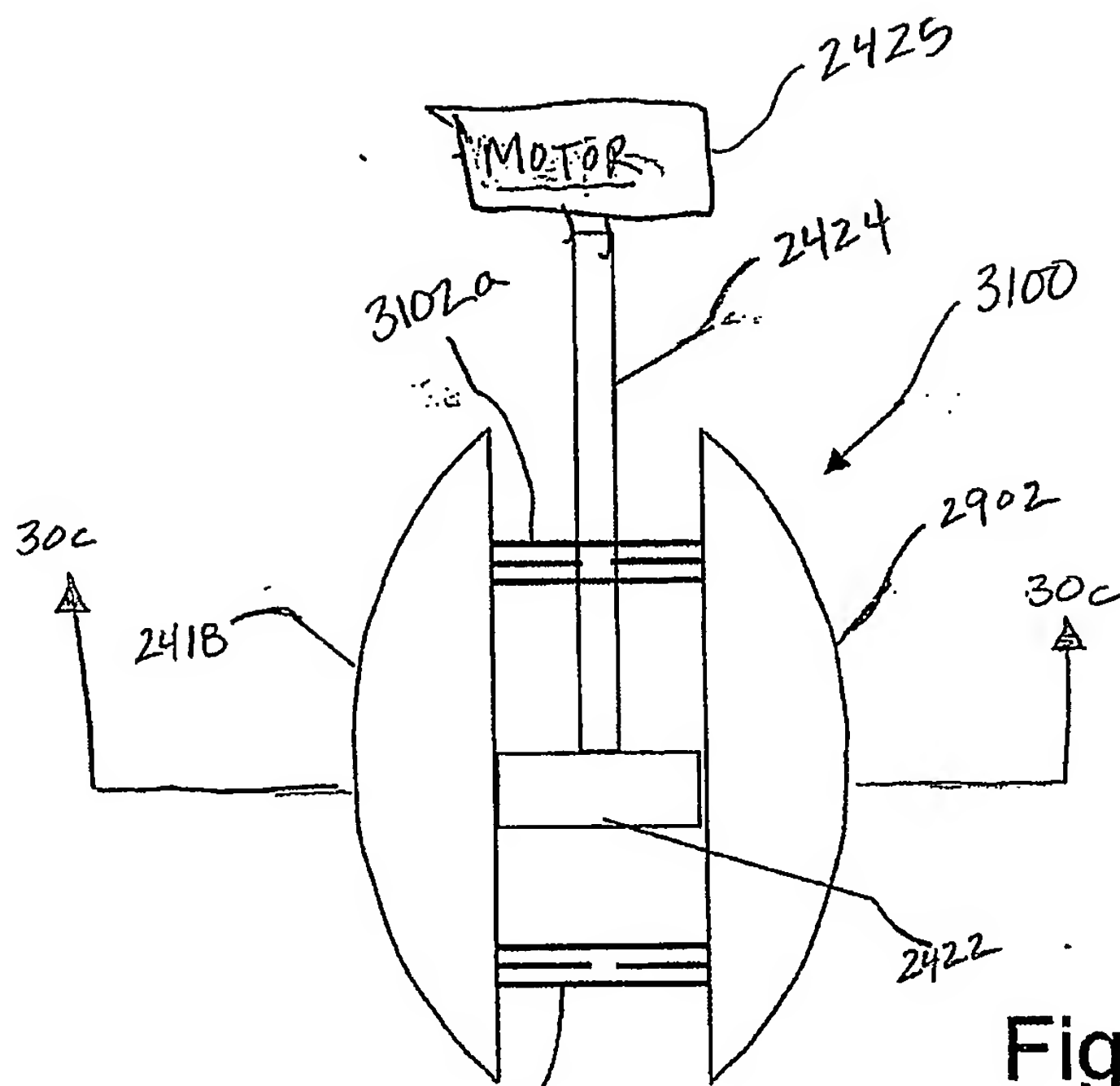


Fig. 30a

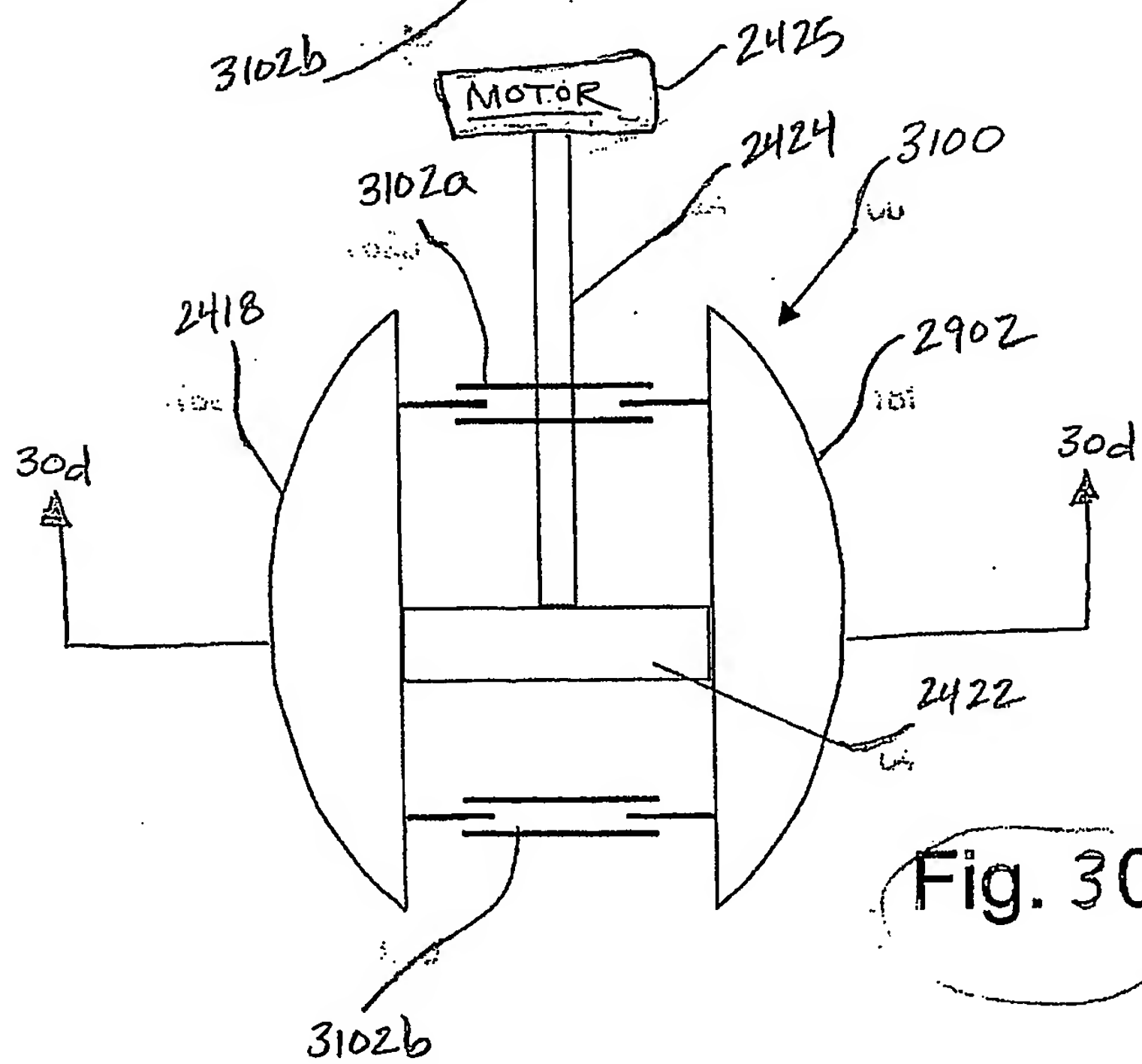


Fig. 30b

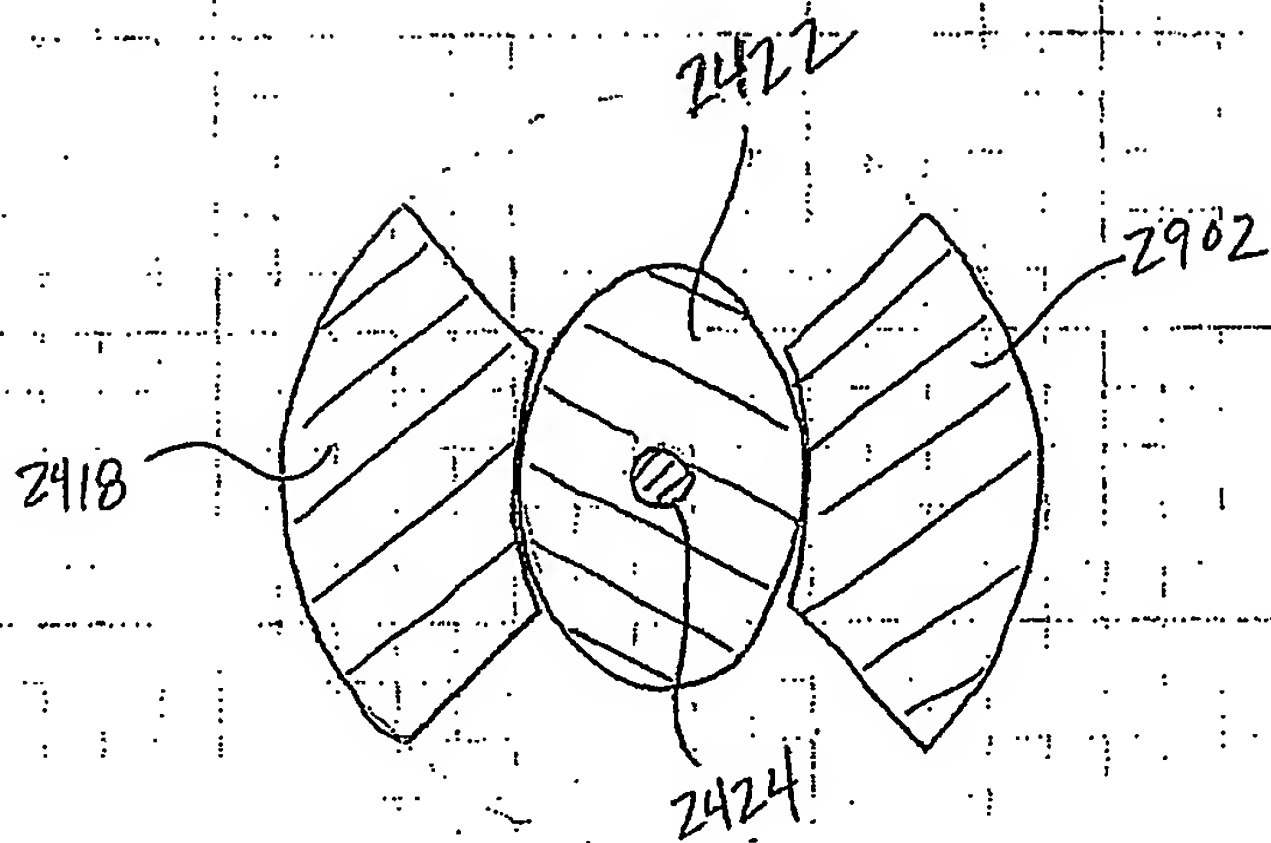


FIGURE 30c

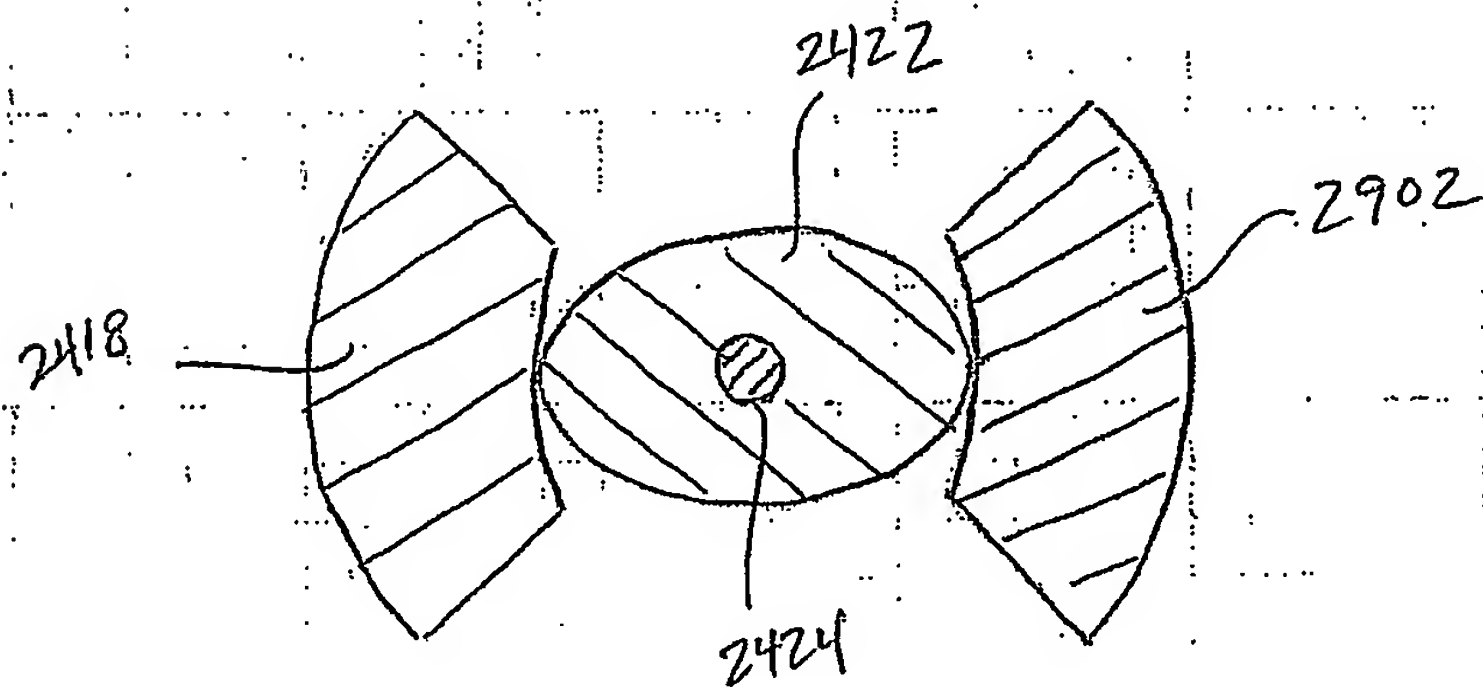
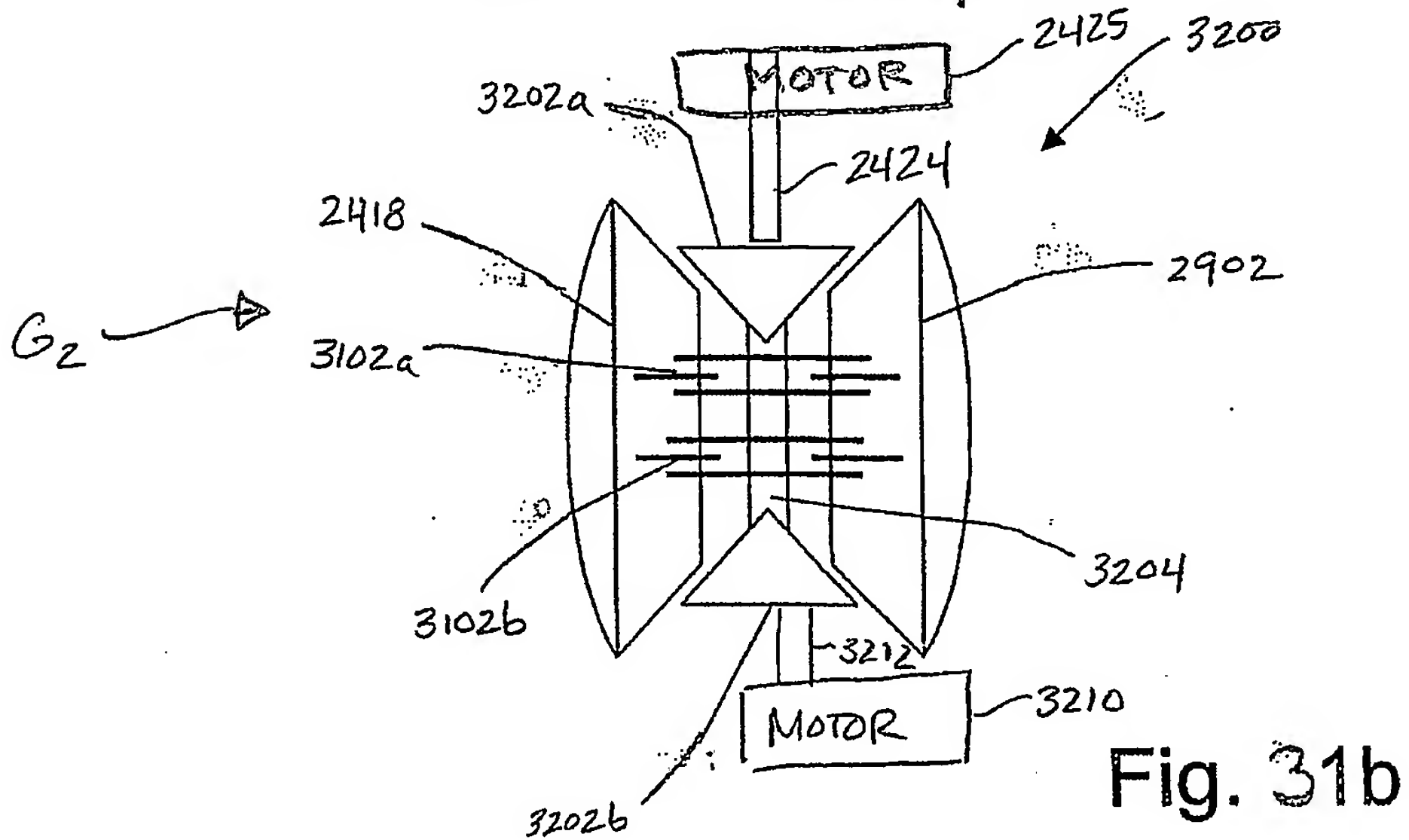
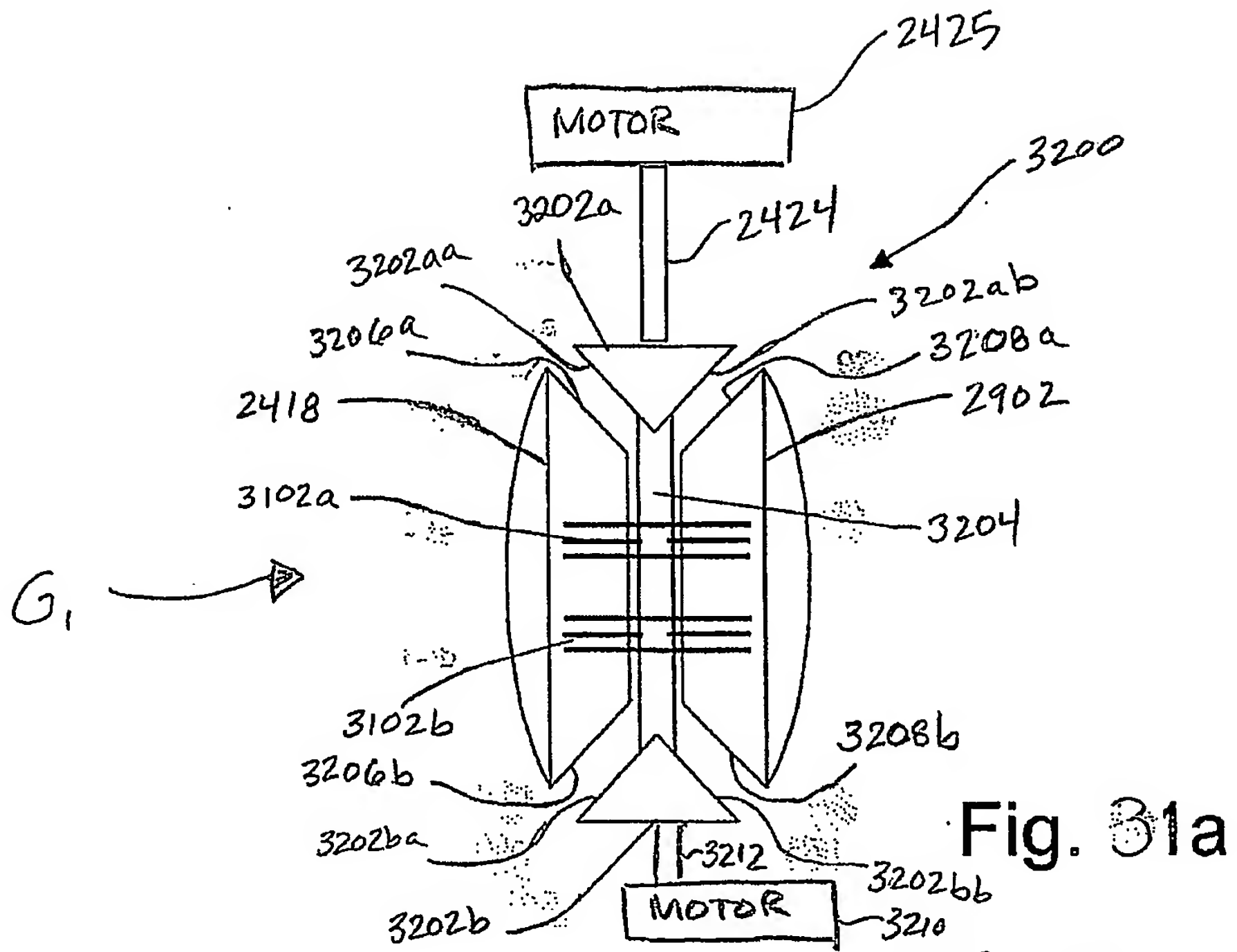


FIGURE 30d



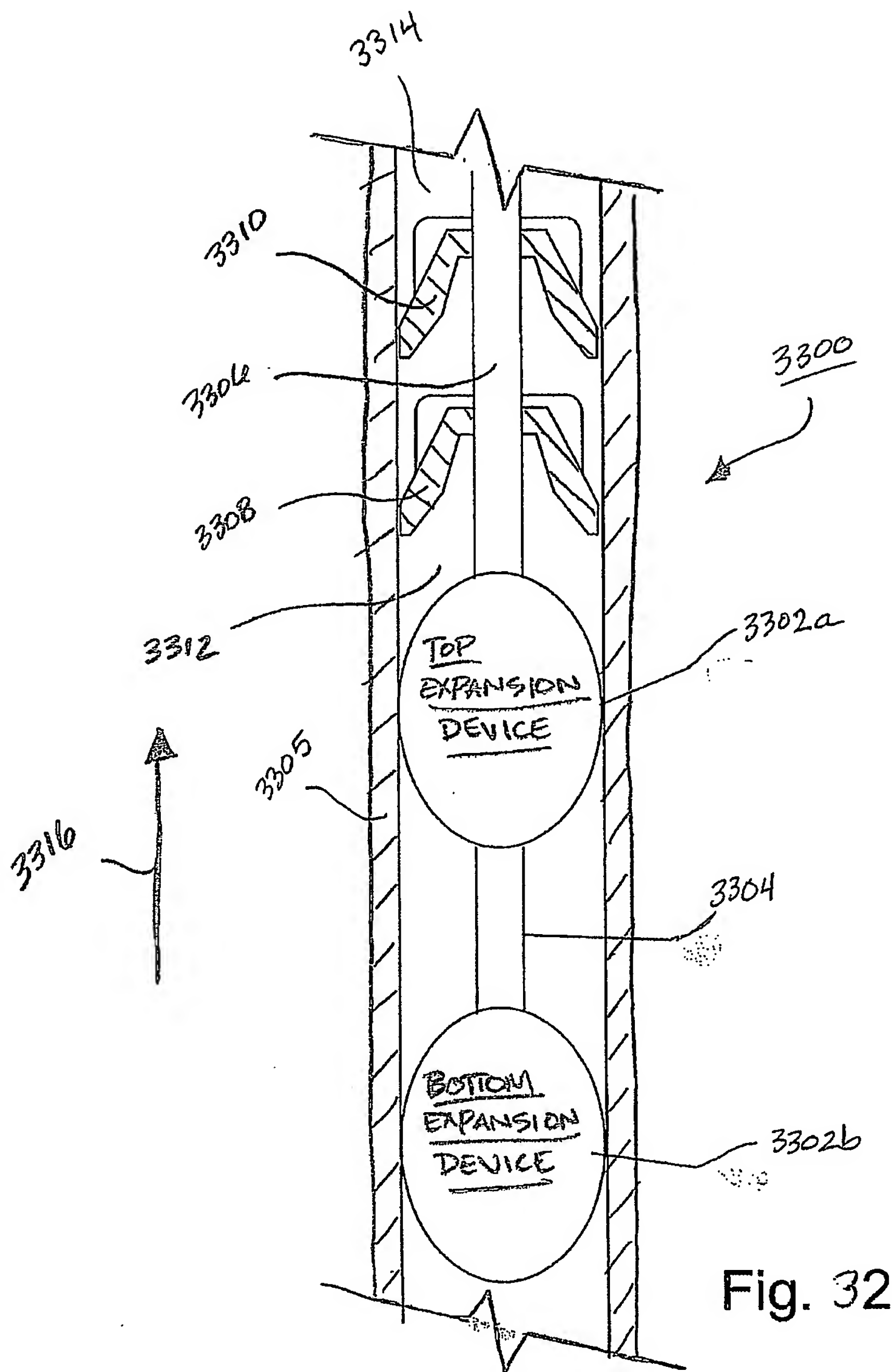


Fig. 32



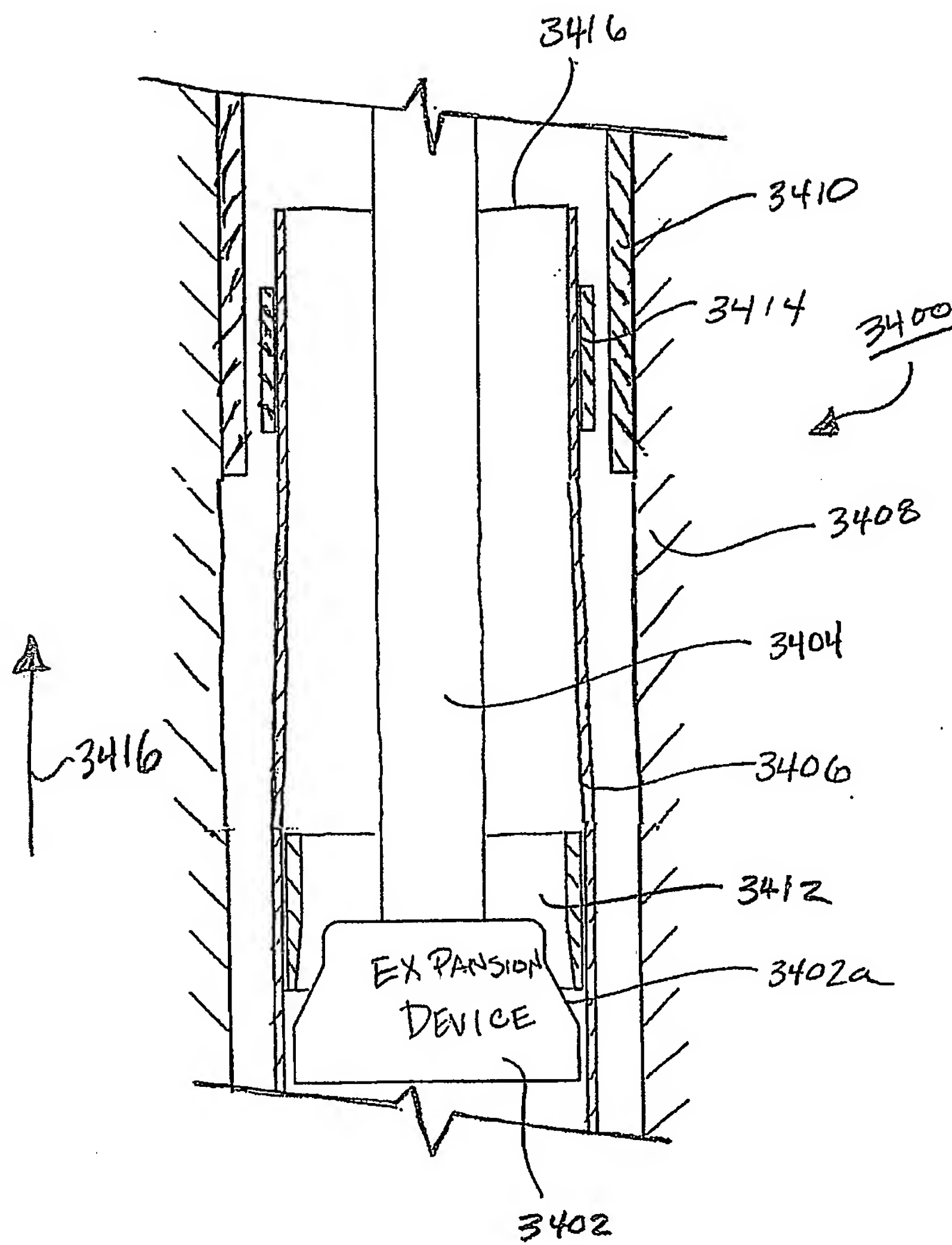


Fig. 33a

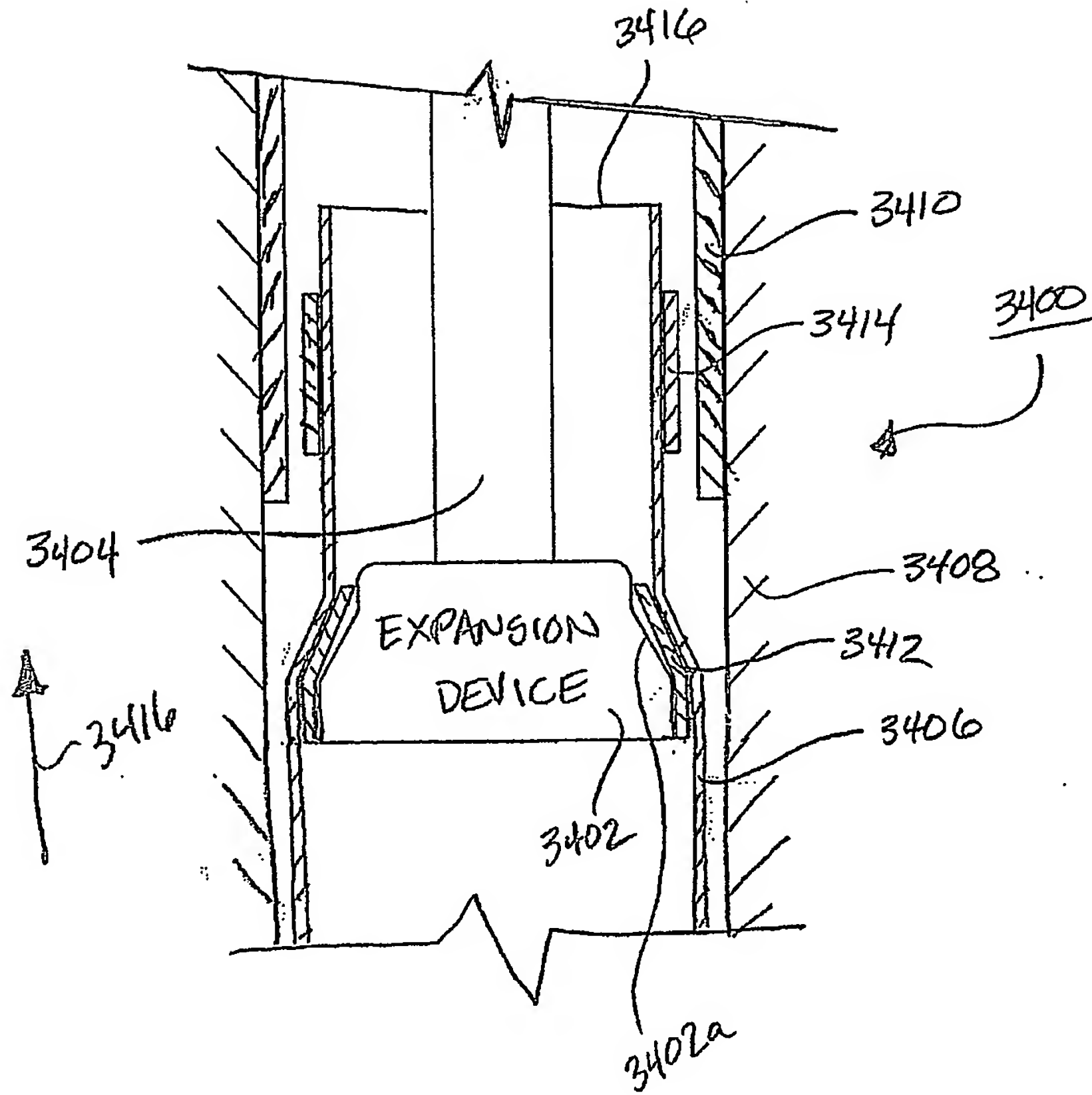


Fig. 33b

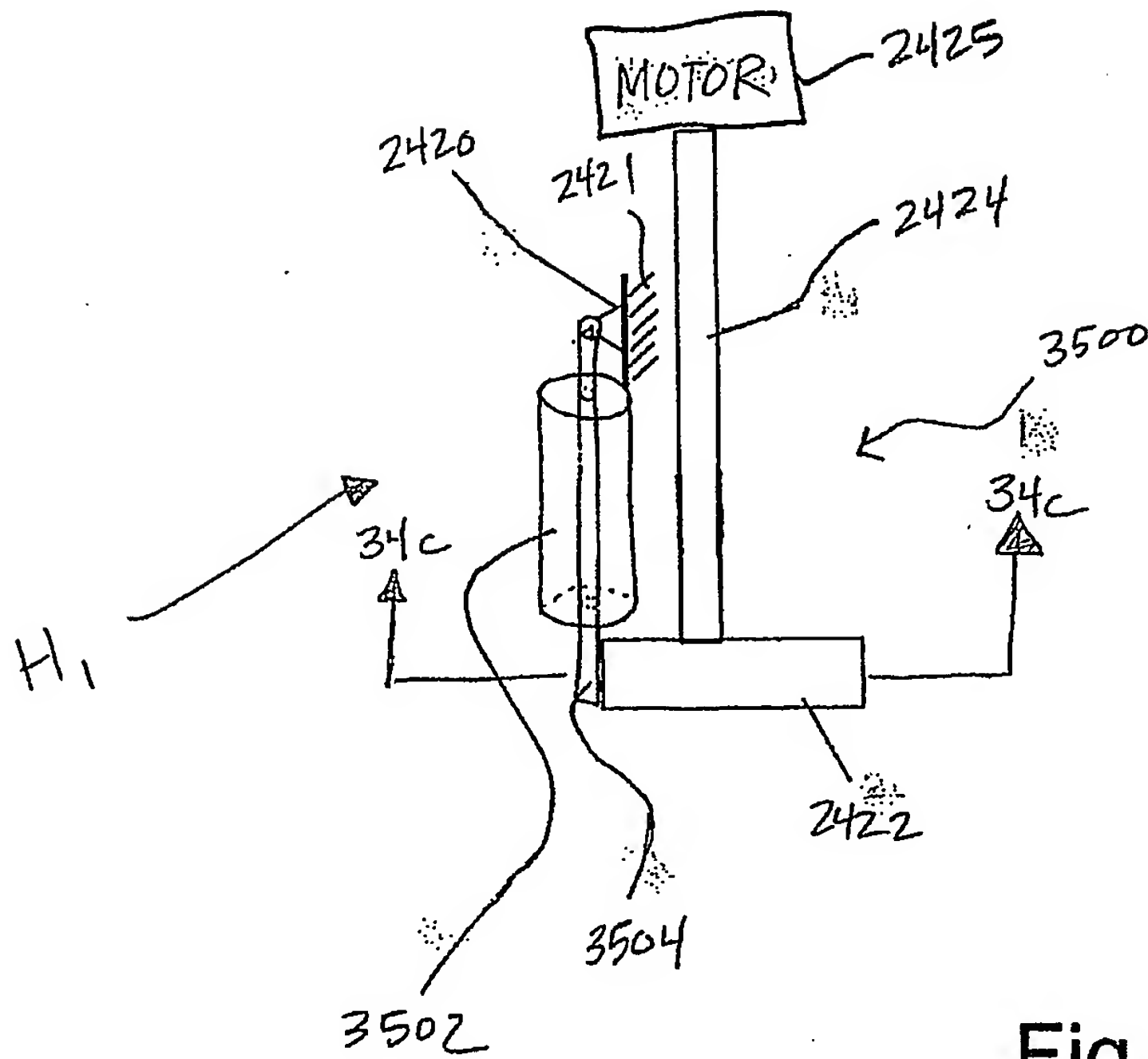


Fig. 34a

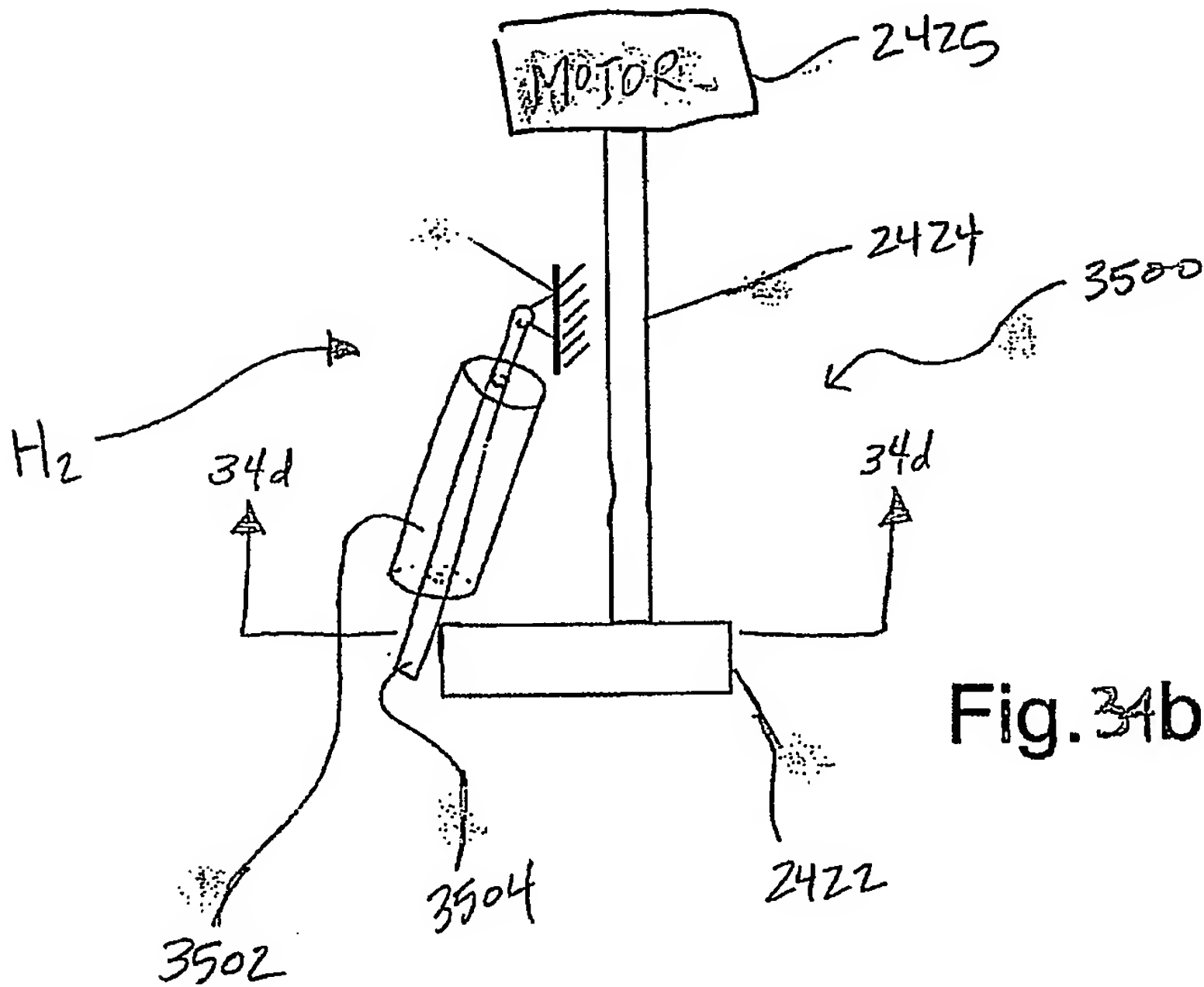


Fig. 34b

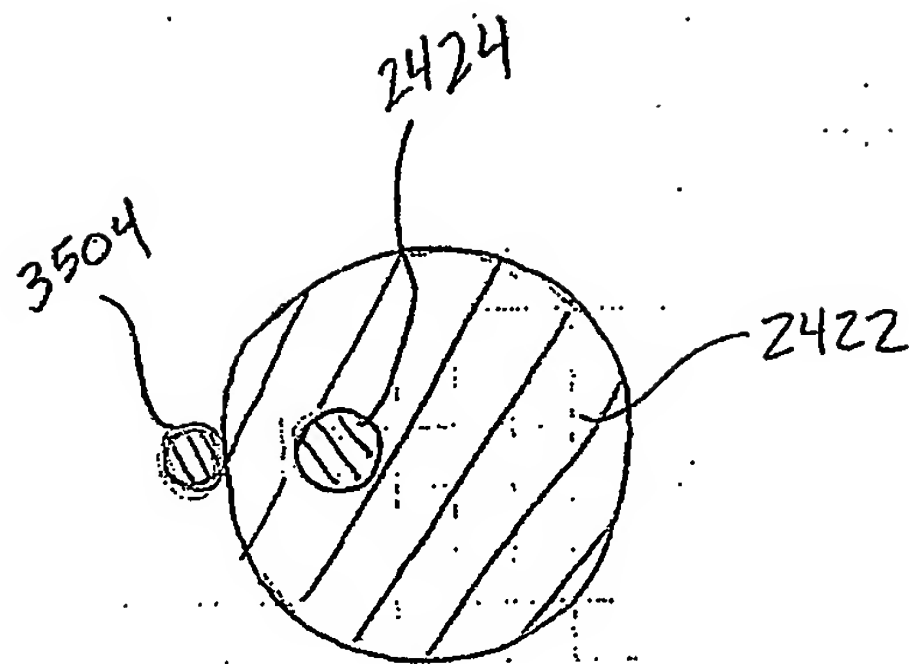


FIGURE 34c

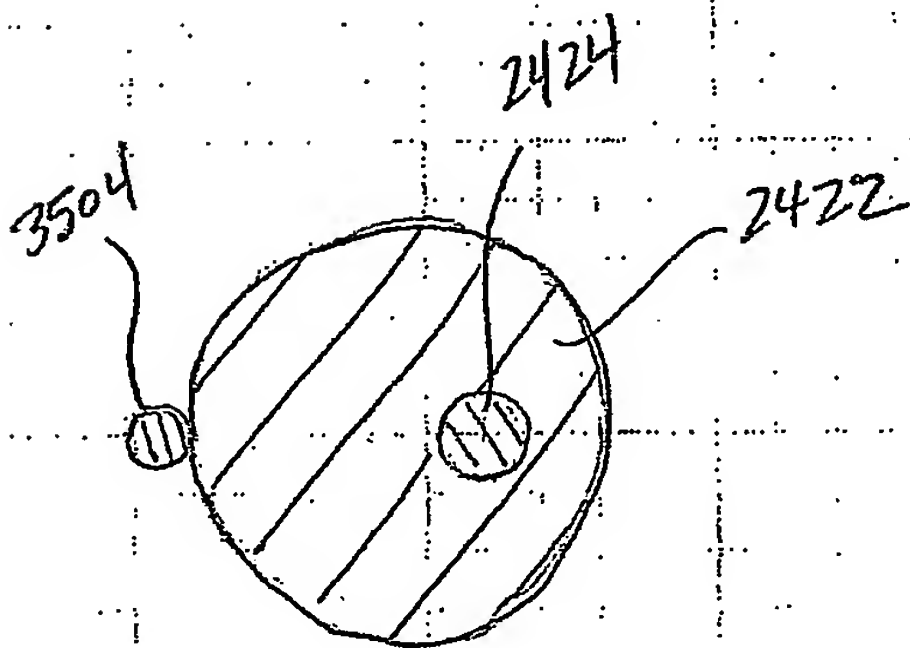
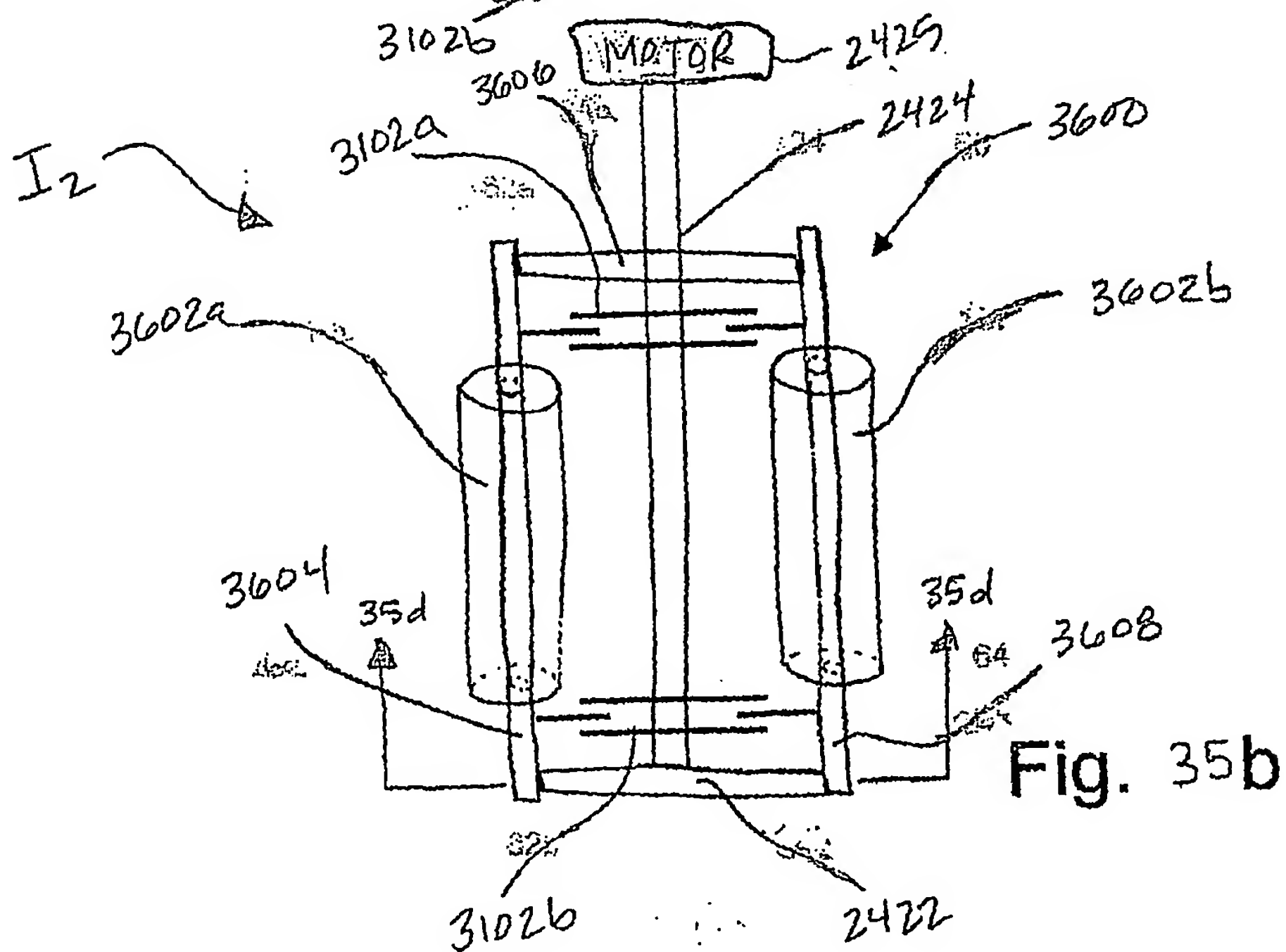
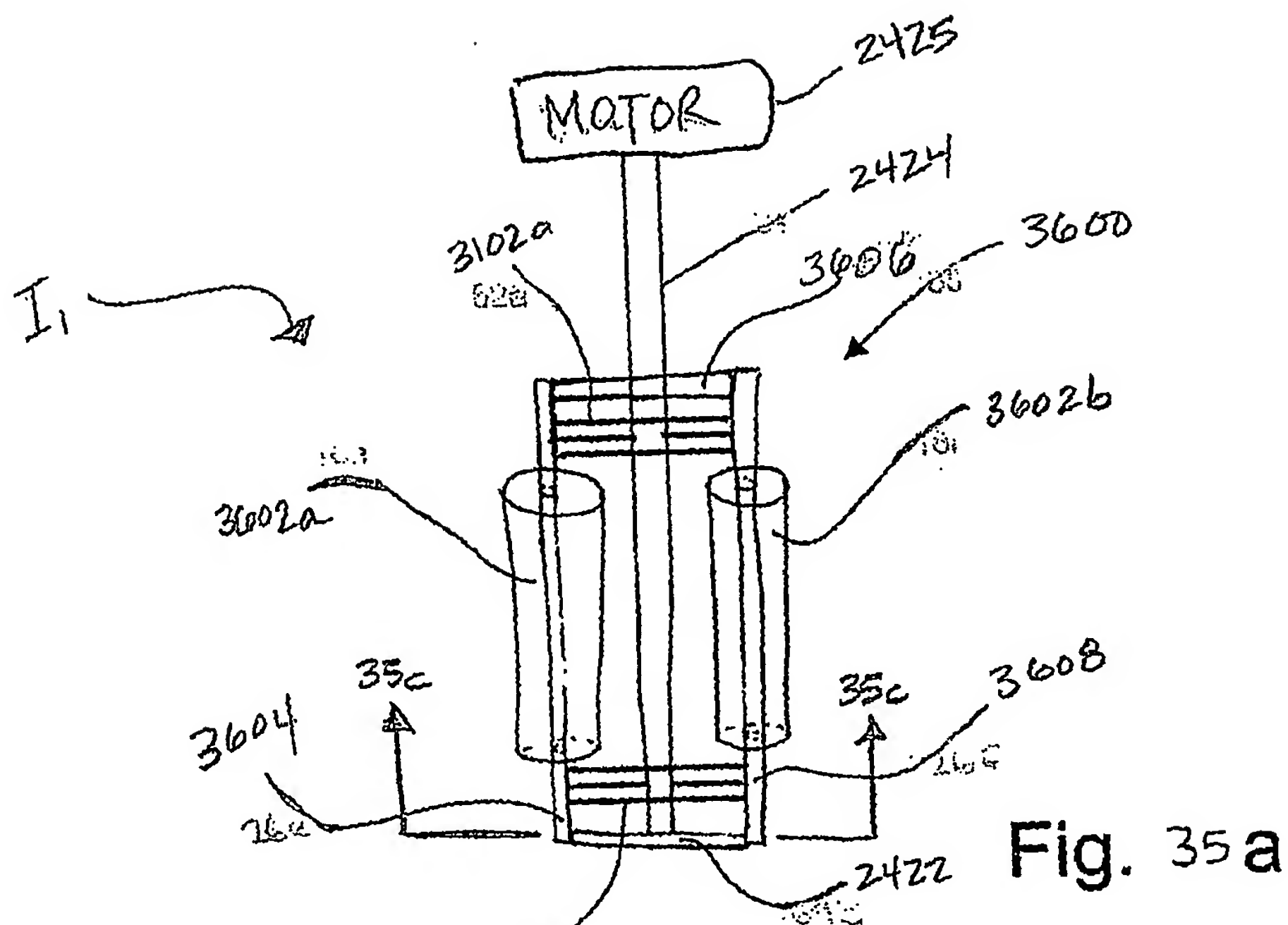


FIGURE 34d



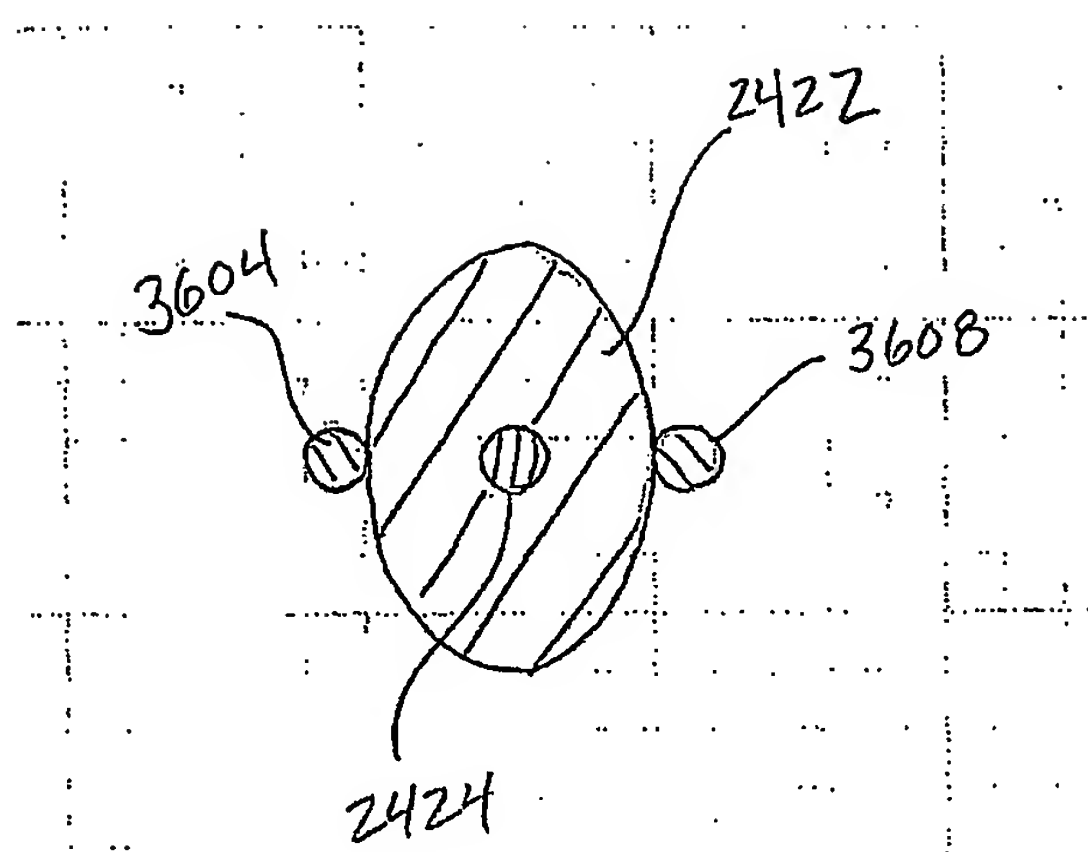


FIGURE 35c

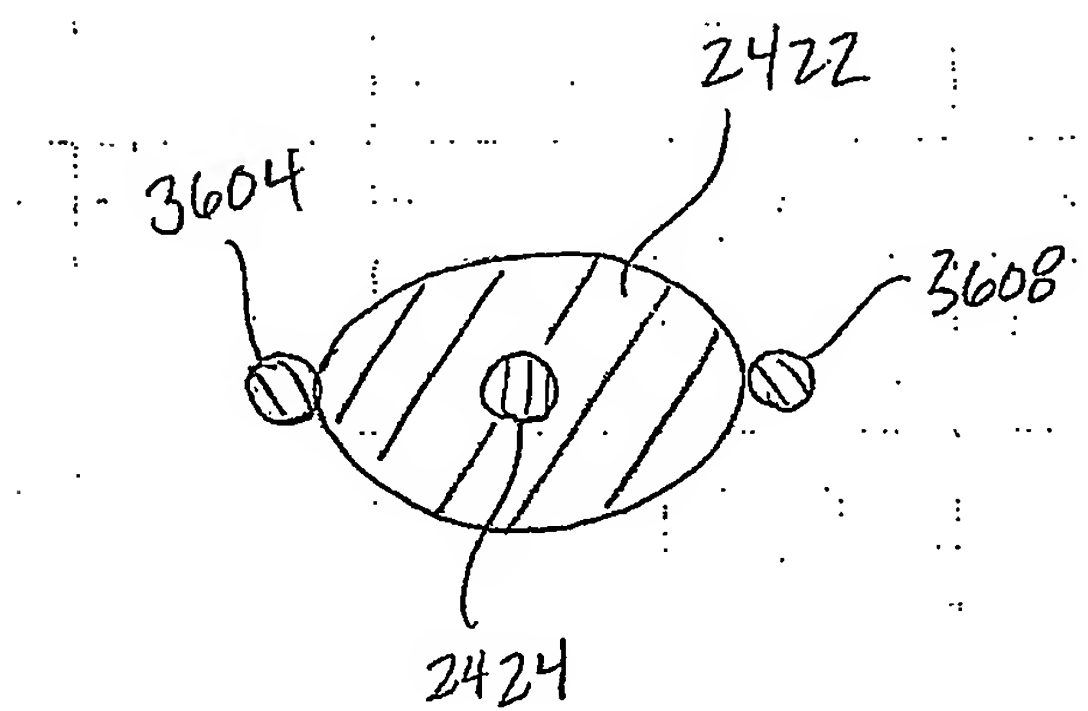
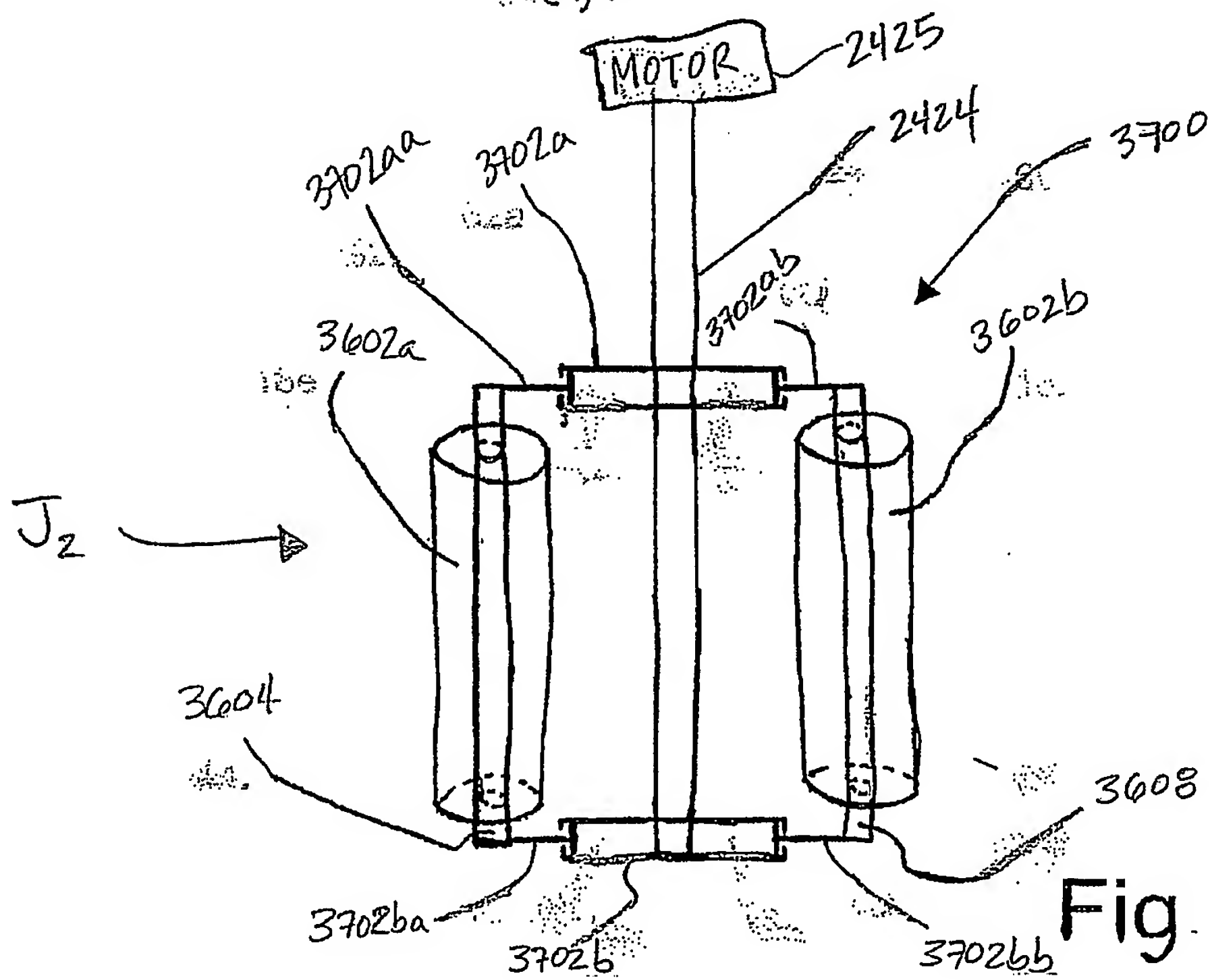
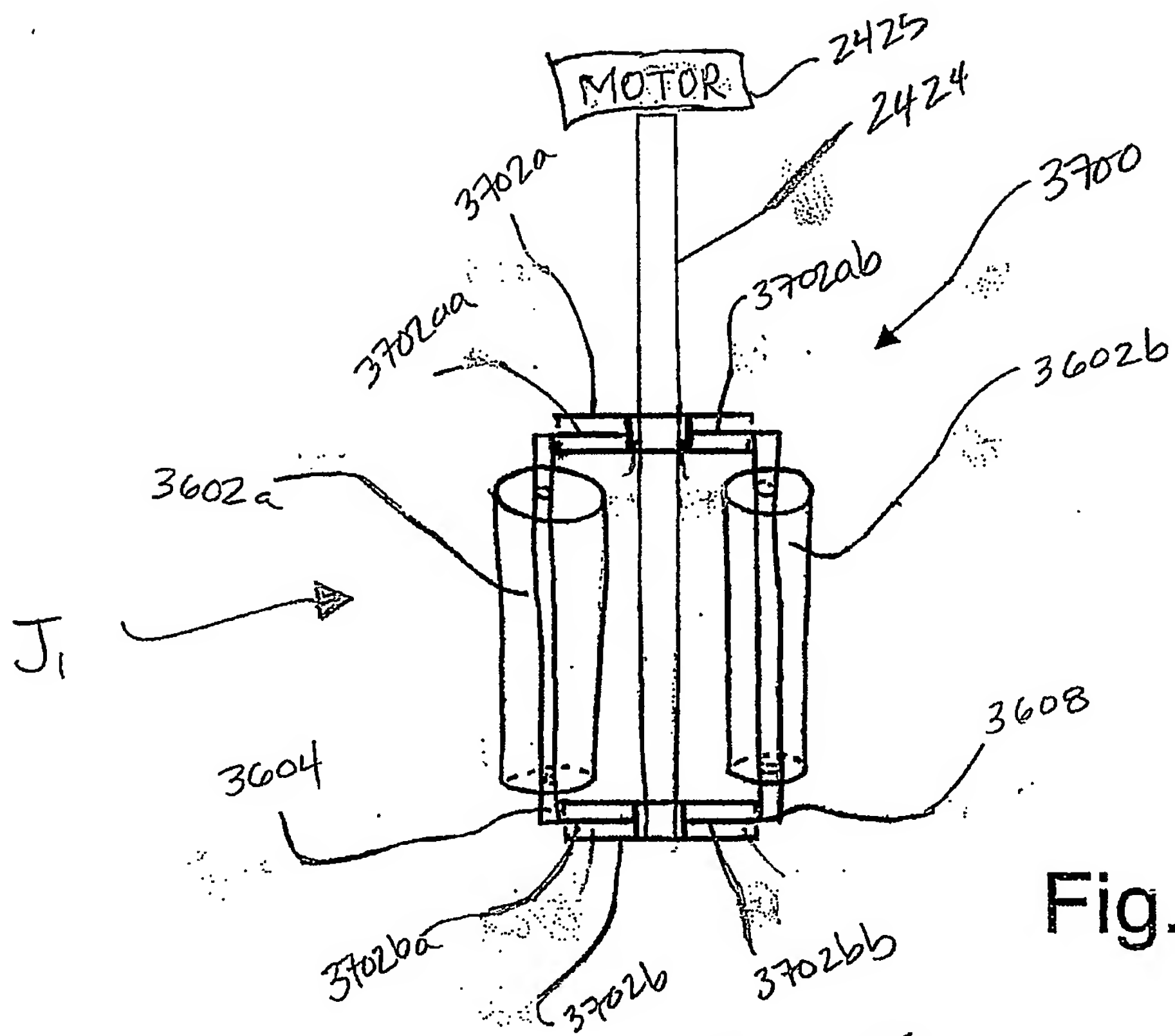
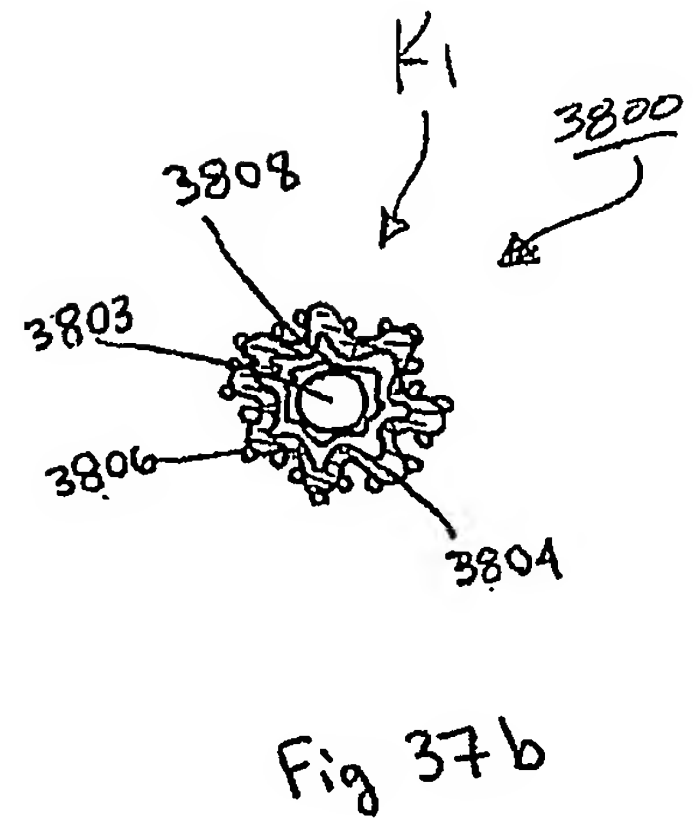
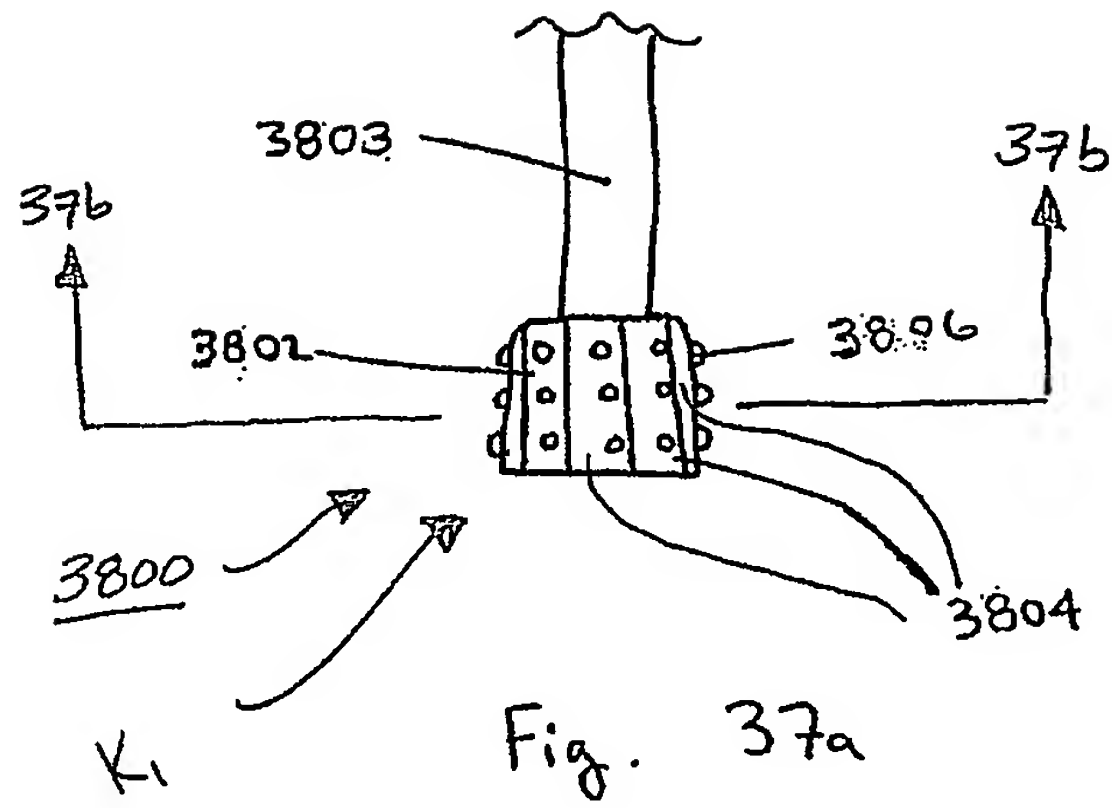


FIGURE 35d







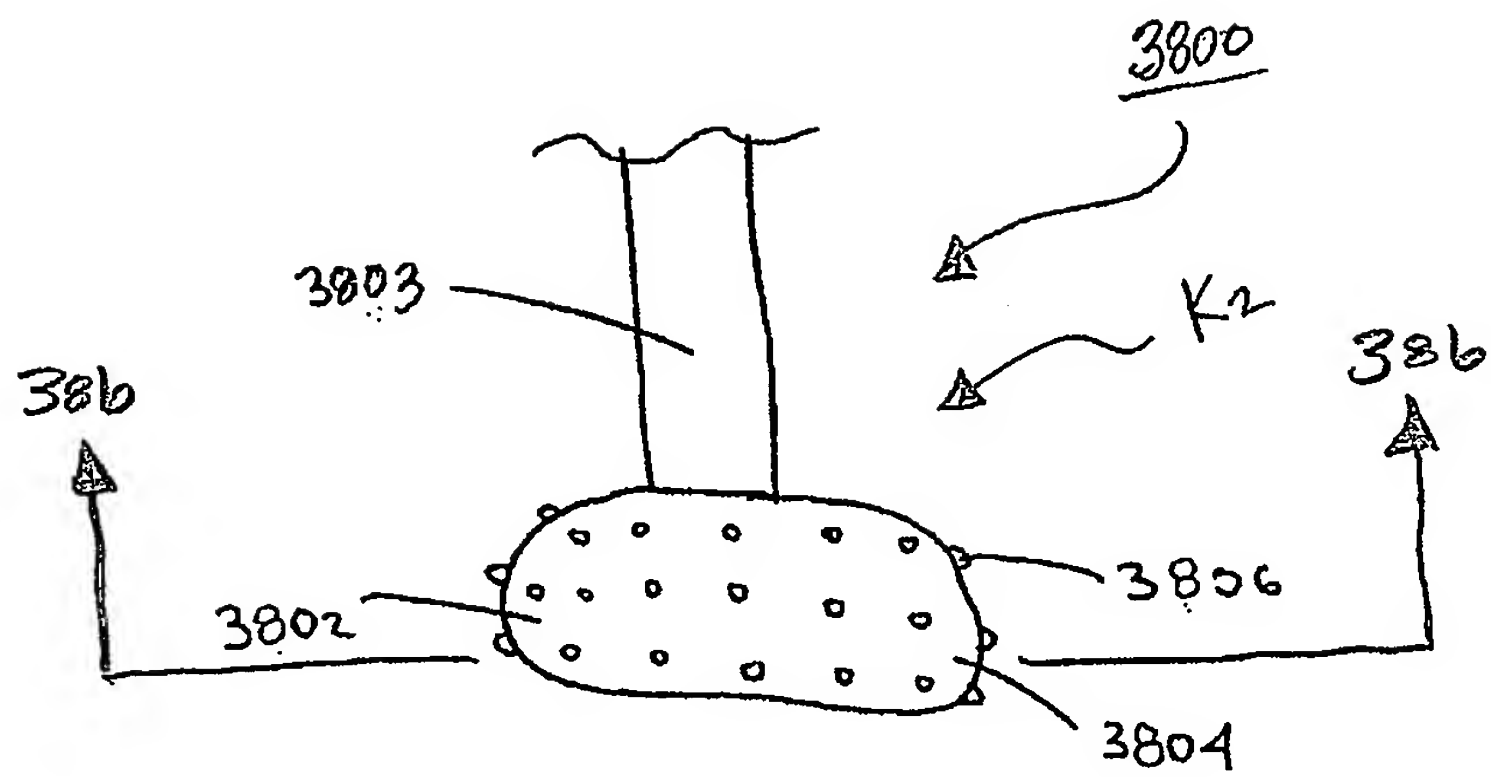


Fig 38a

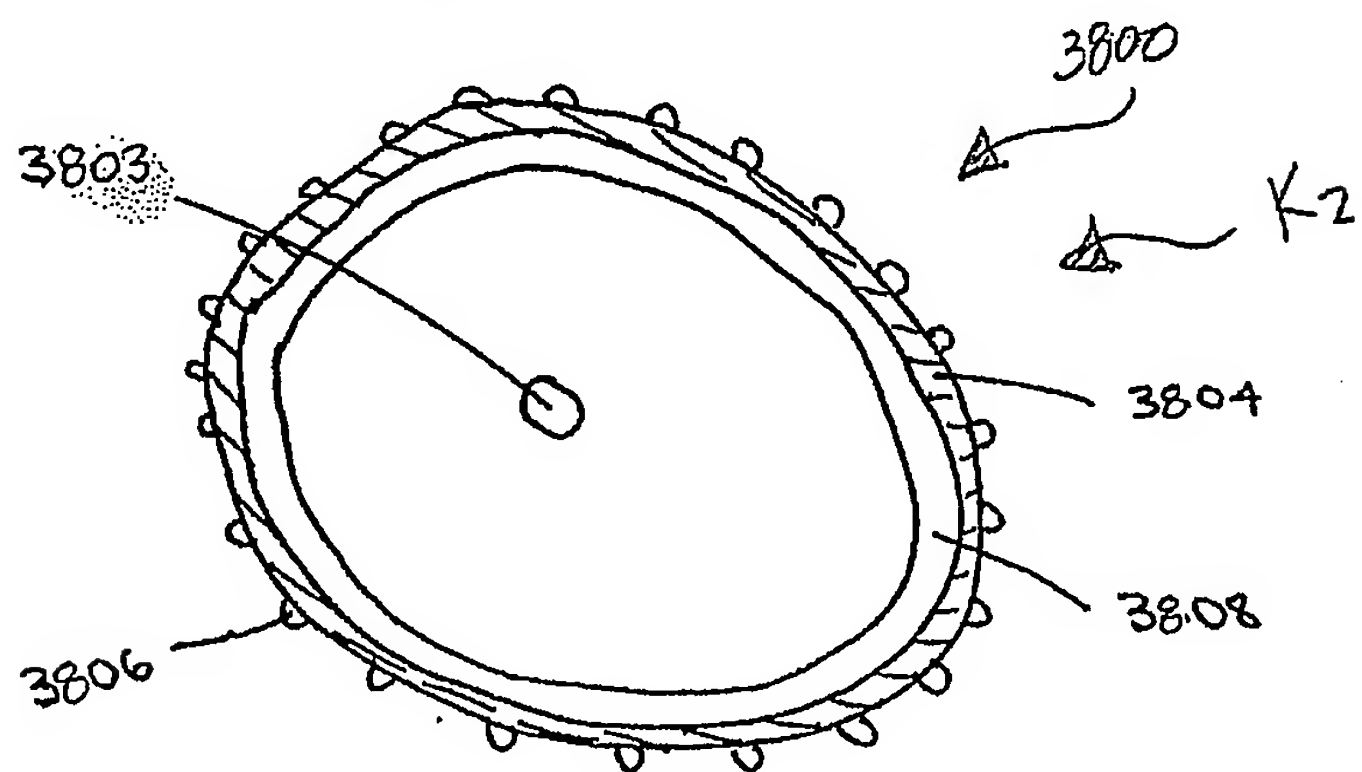
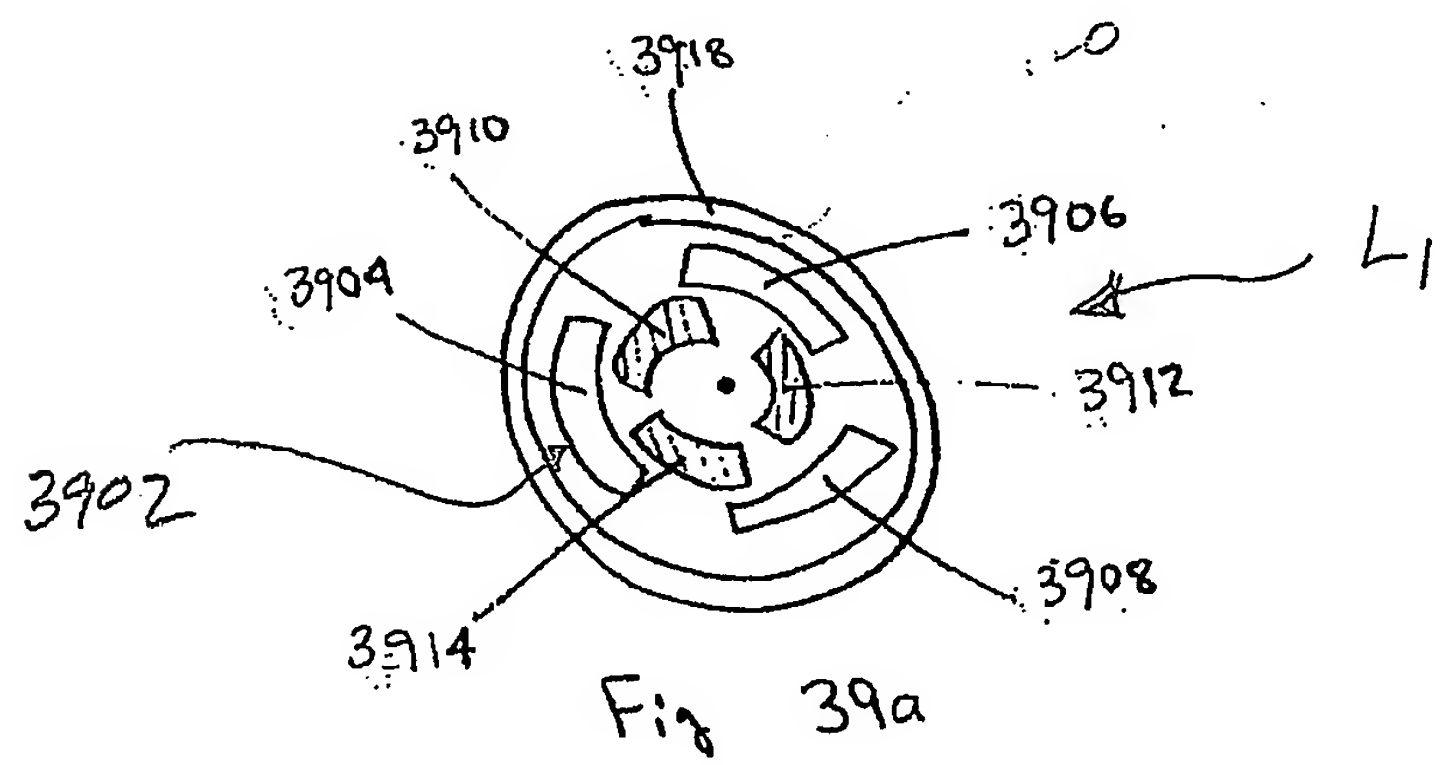
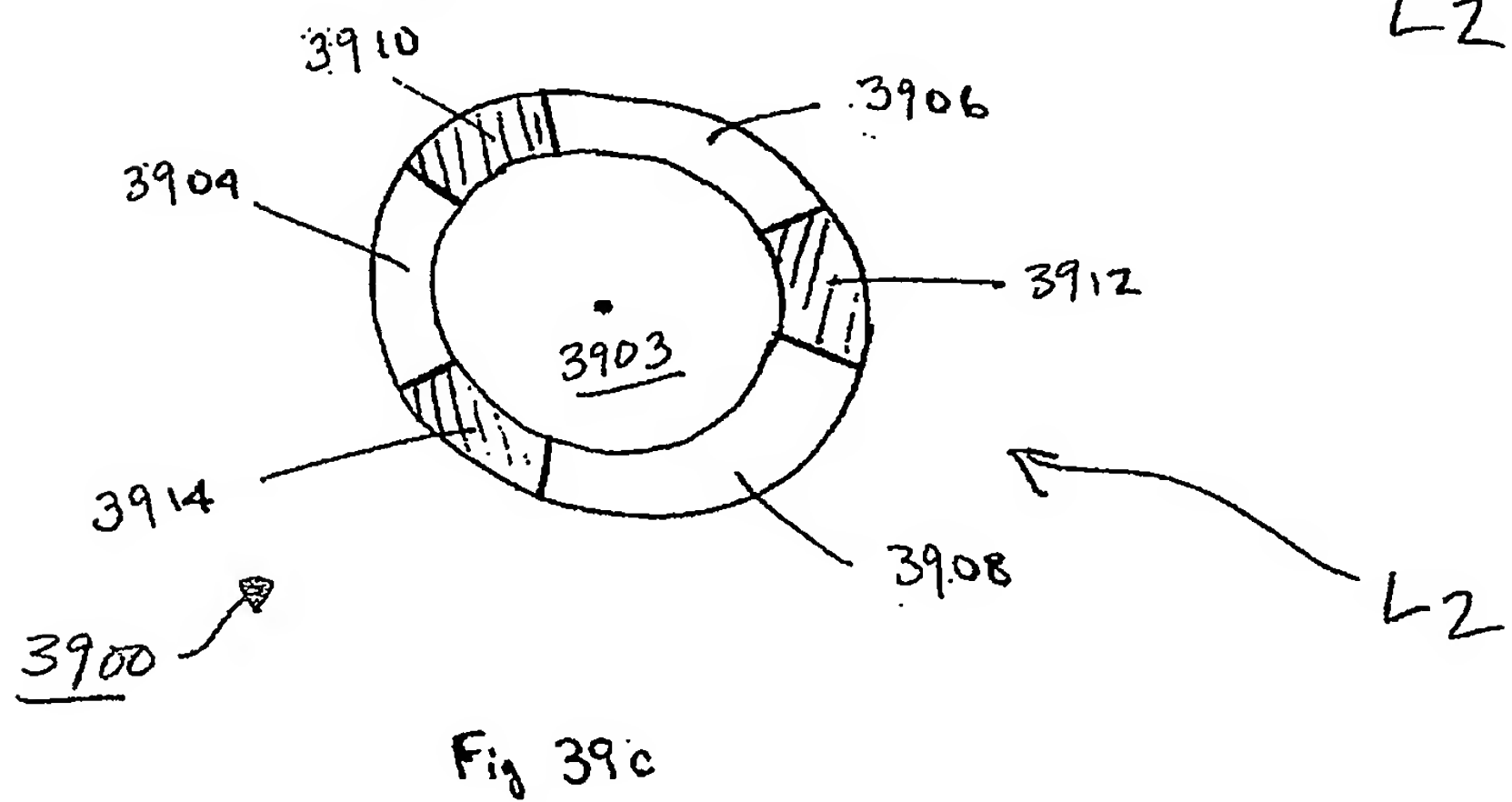
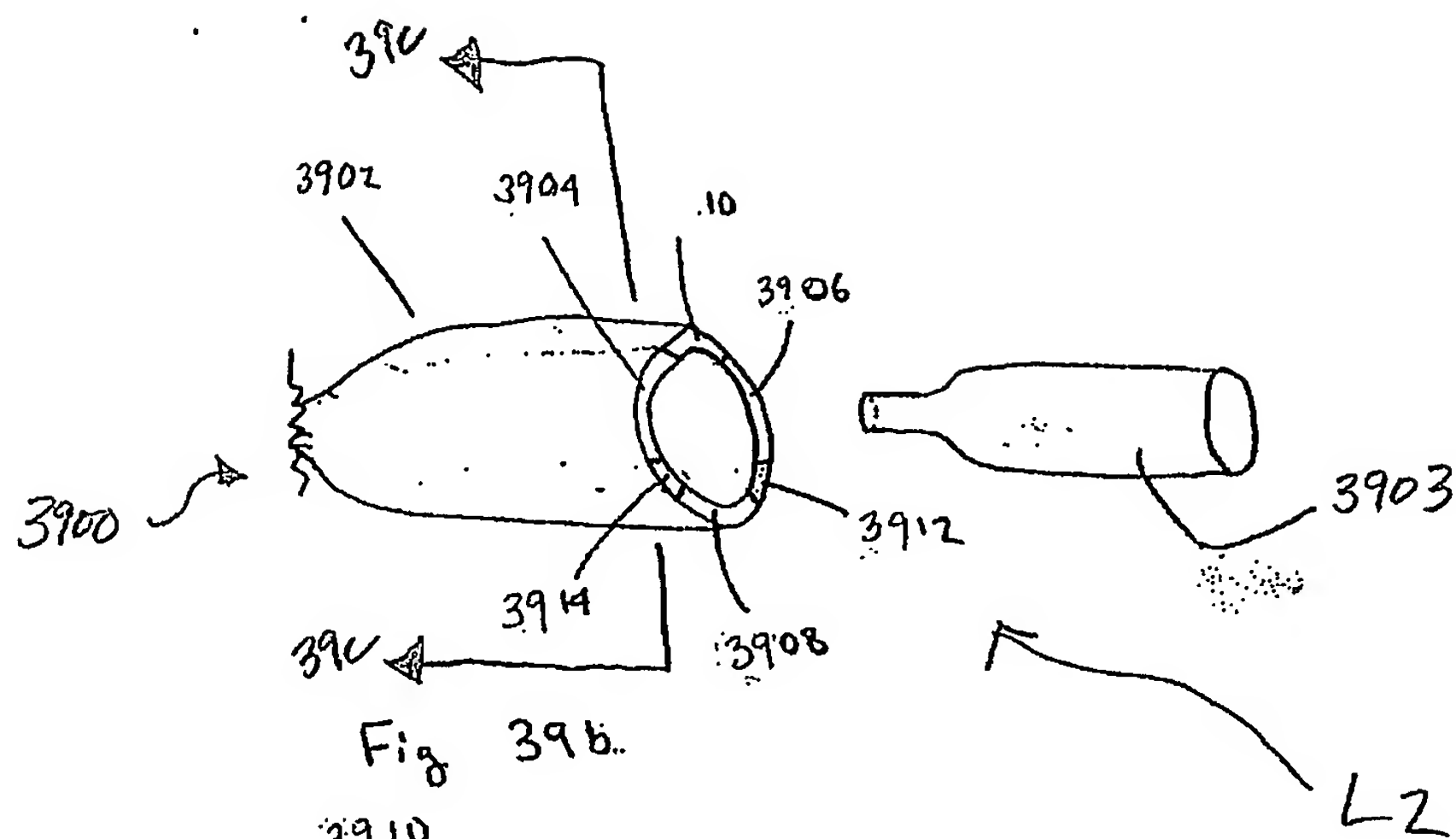
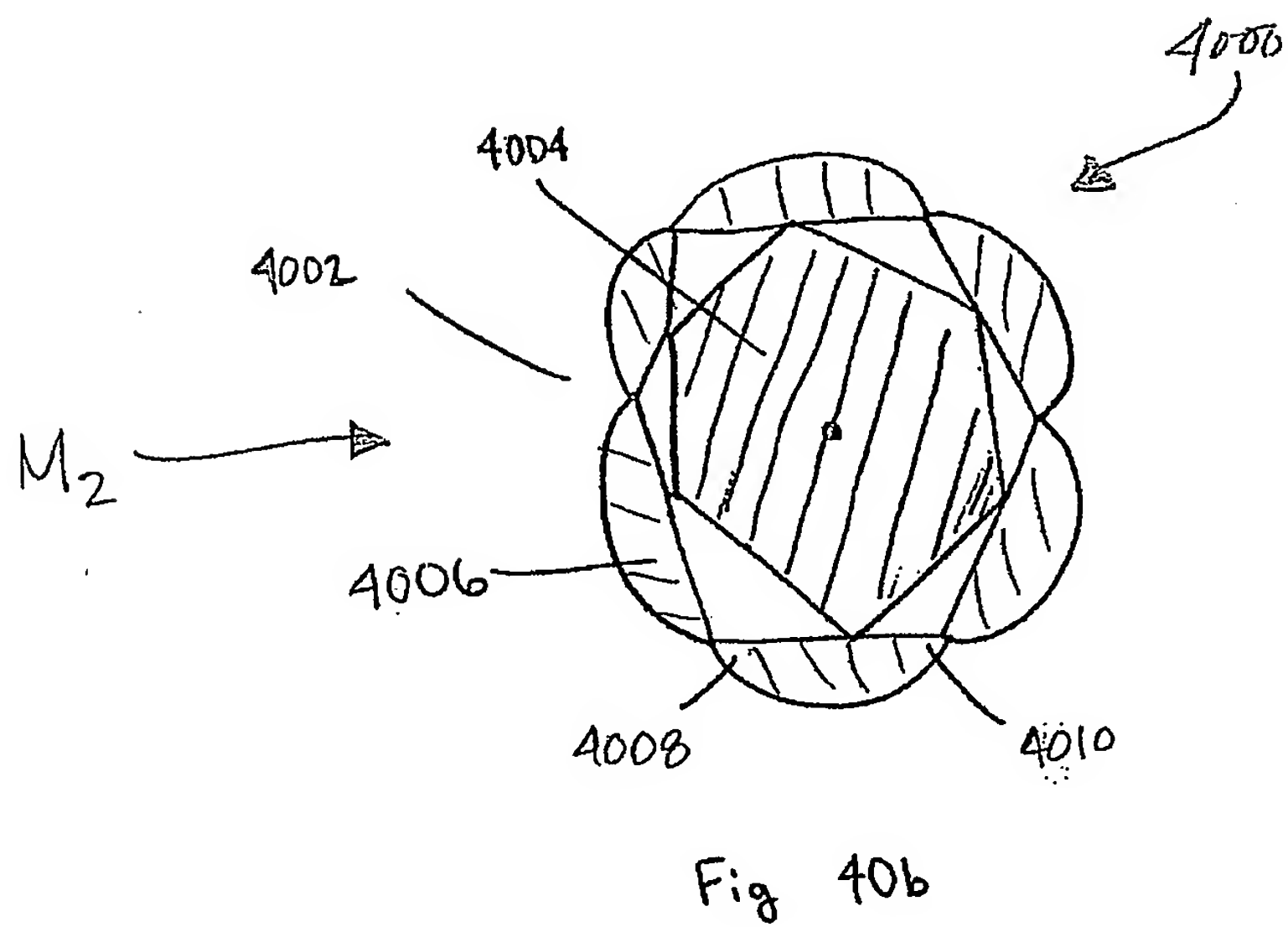
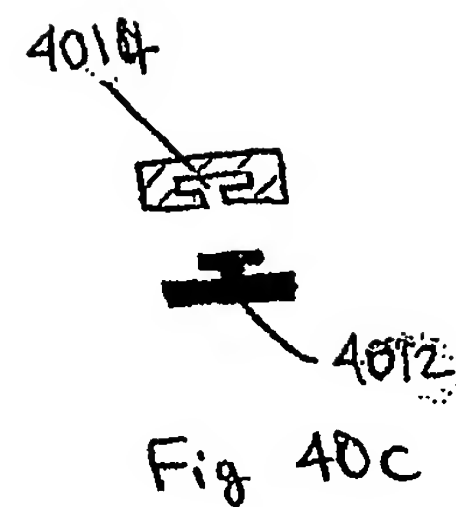
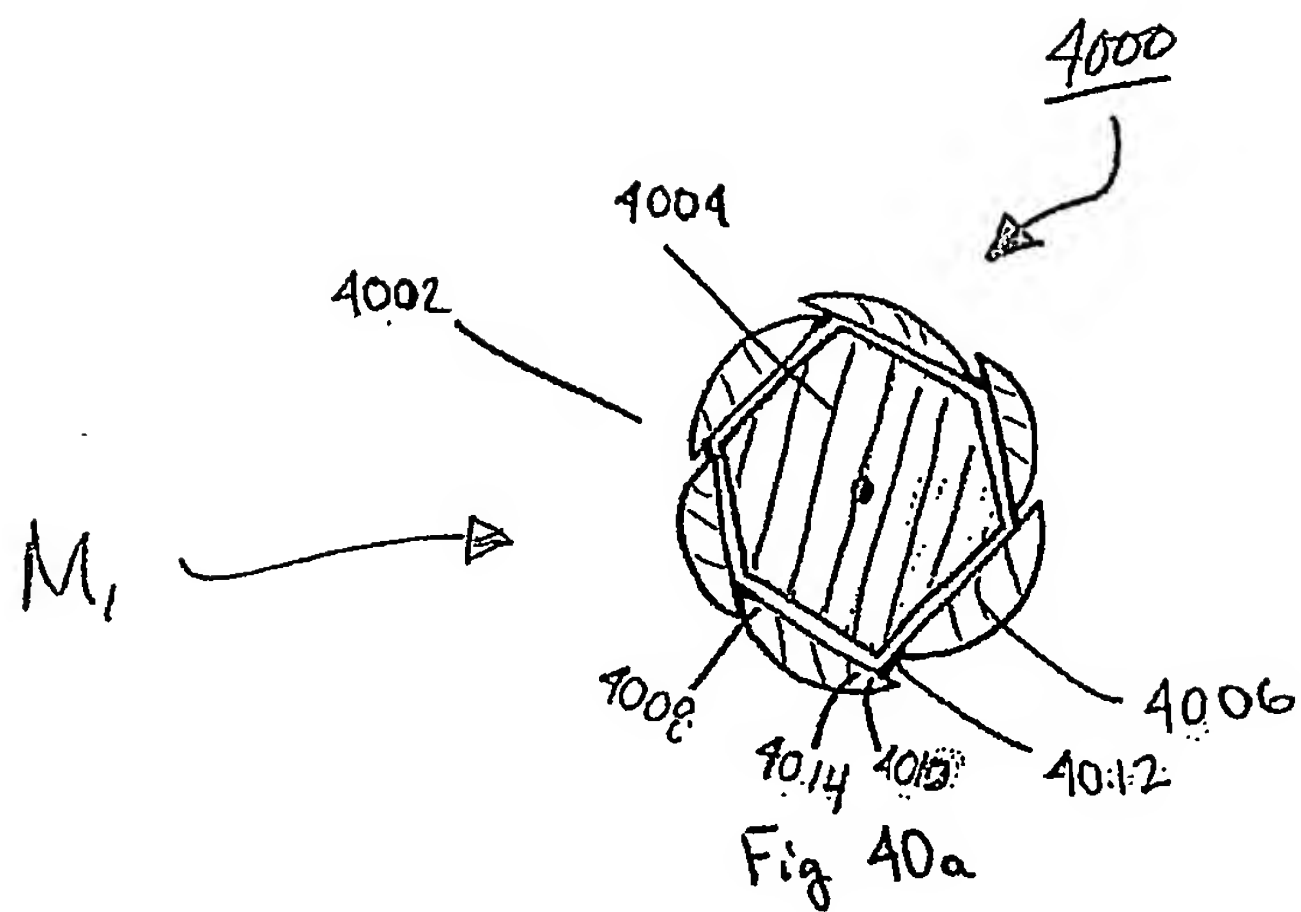


Fig 38b





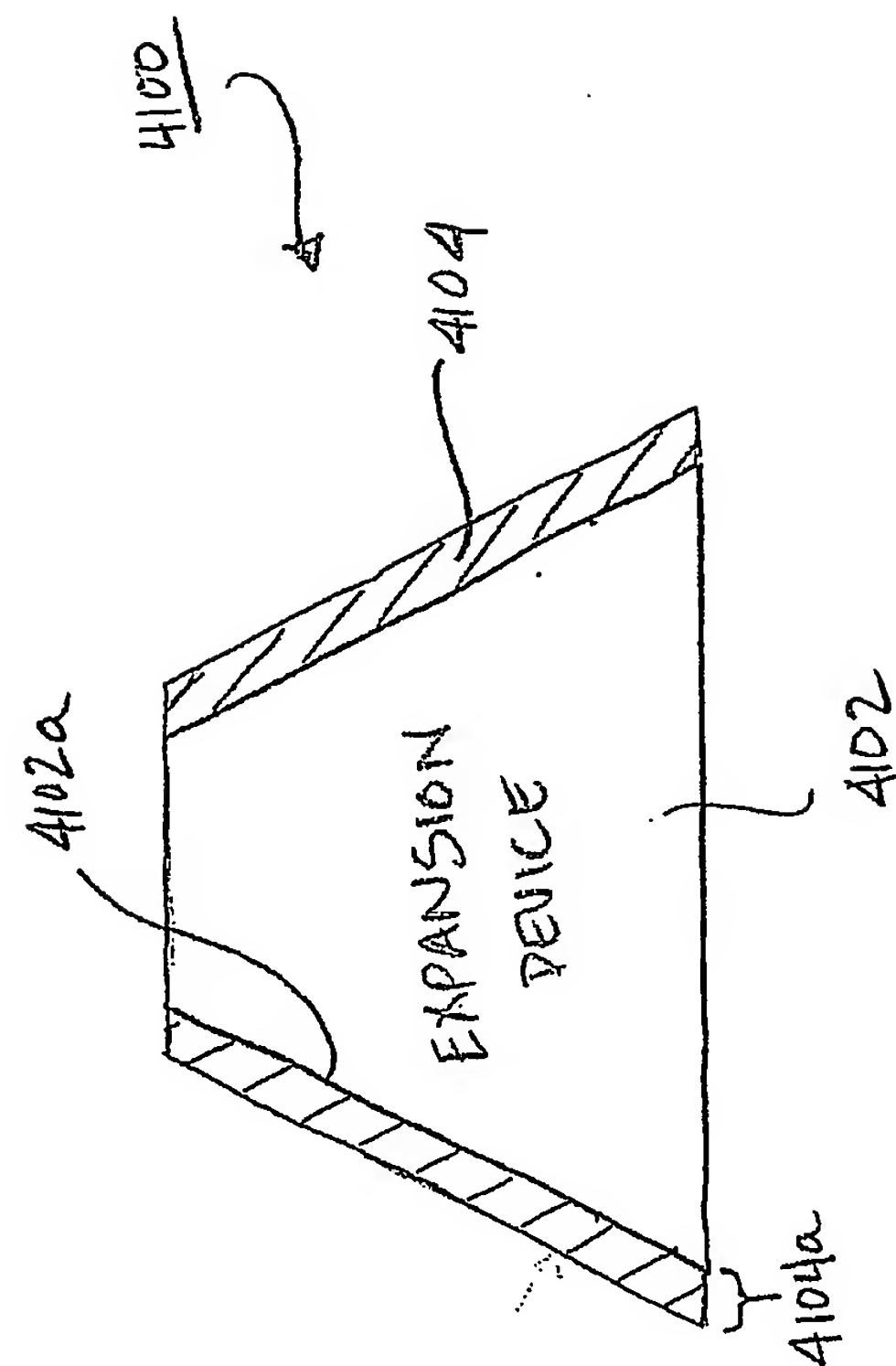


FIGURE 41a

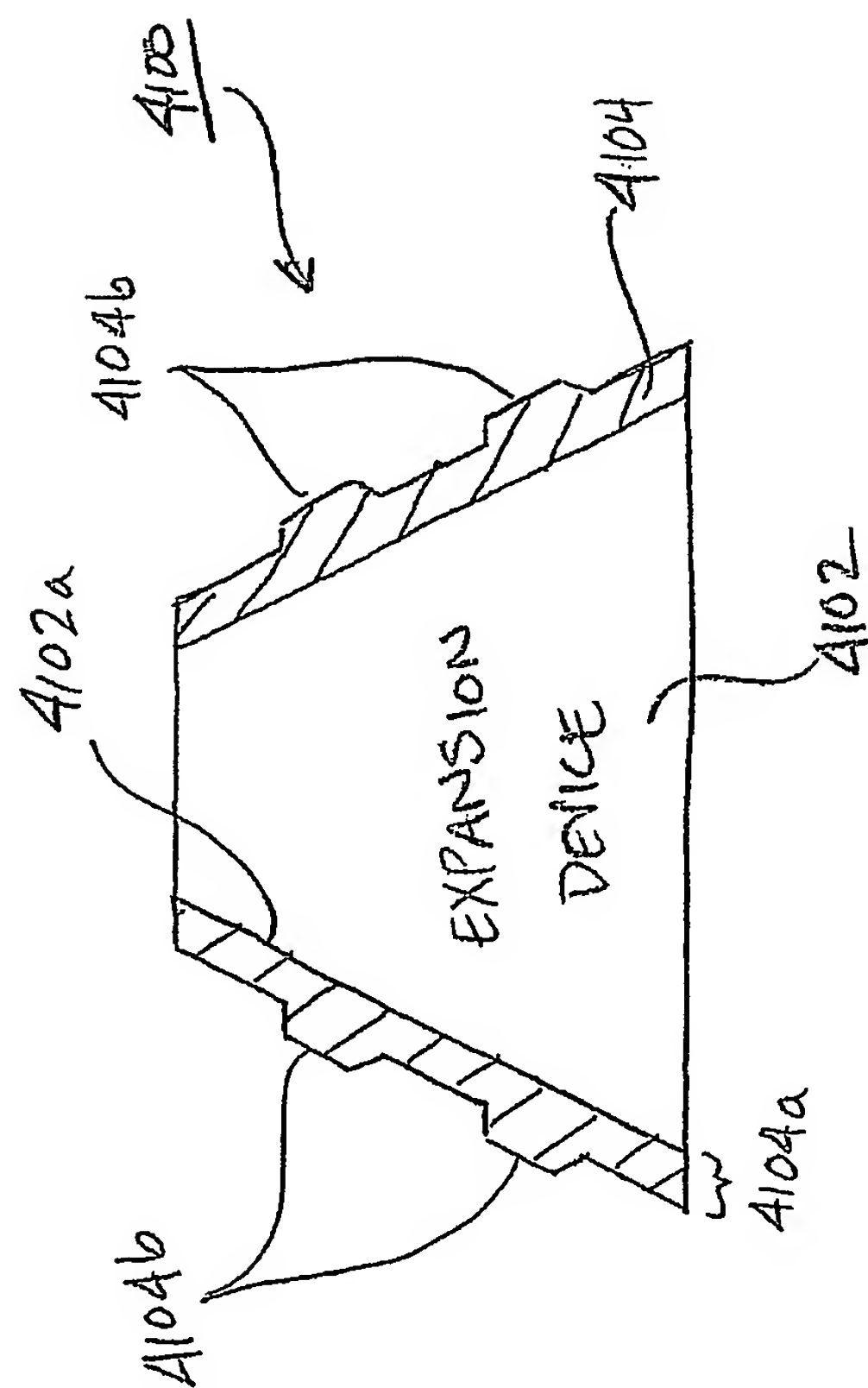


FIGURE 41b

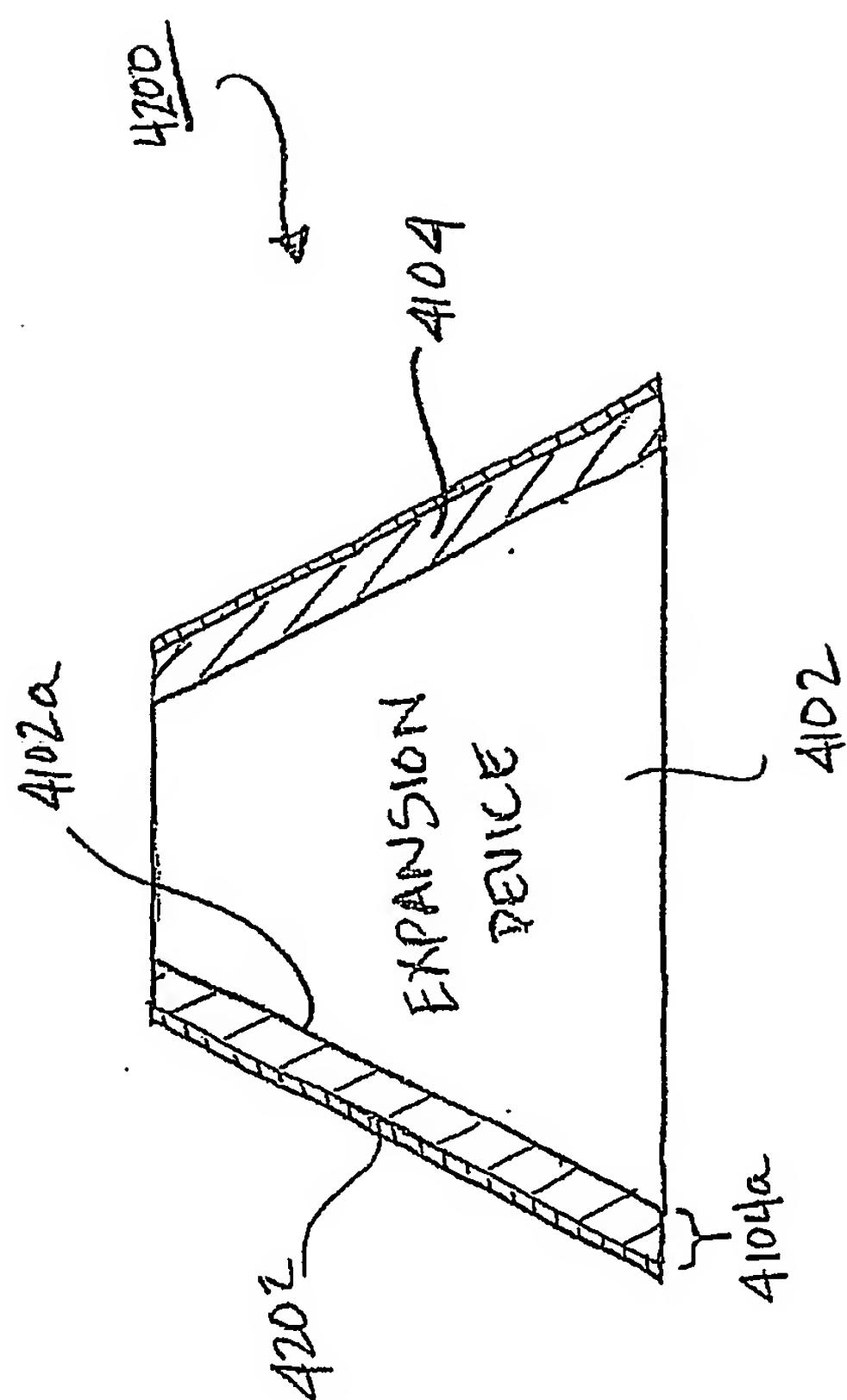


FIGURE 42a